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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

WING-OPERATION TESTS OF THE CHANCE-VOUGHT F4U-1D

AIRPLANE IN THE LANGLEY FULL-SCALE TUNNEL

TED No. NACA 2371

By

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Wing-operation tests of the Chance-Vought F4U-1D airplane were made in the Langley full-scale tunnel in order to investigate the difficulties encountered aboard aircraft carriers in spreading and folding the wings of the subject airplane in high winds. This investigation included a yaw-angle range of from -45° to 30° and a range of tunnel airspeeds of from 0 knots to that at which the upstream wing refused to spread. Tests were conducted on a service airplane and, later, on another F4U-1D airplane incorporating modifications made to improve wing-spread operation.

The data are presented in graphical form as composite plots showing the variations of hydraulic pressure and wing folding-strut loads with changing angle of wing rotation for the range of yaw positions. The time intervals required for wing operation, and the airspeeds at which wing-spread refusal occurred, are presented in tabular form for the original and modified airplanes.

The results showed that, for the range-of-yaw positions and airspeeds investigated, the most critical condition from the standpoint of spreading the wings occurred with the airplane at the 30° yaw position. The folding characteristics in every condition tested were satisfactory.

The greatest improvement towards aiding the wing-spread operation was accomplished by increasing the hydraulic pressure available to at least the 1800 pounds per square inch used during the tests.

It was also found that some aid may be obtained in spreading by operating the cowl flaps, or by moving the control stick toward the wing having the greatest difficulty in spreading.

A method is presented whereby it is possible to evaluate pressure required for wing-spread operation up to and beyond the wing-refusal limits of the original airplane. An illustrative comparison of the values obtained by this method and by tests is included in the text.

INTRODUCTION

The Bureau of Aeronautics, Navy Department, requested wing-operation tests of the Chance-Vought F4U-1D airplane to be made in the Langley full-scale tunnel. These tests were occasioned by the reports from aircraft carriers that difficulty was experienced in spreading and folding the wings of the subject airplane in high winds. The investigation called for a determination of the airspeeds and yaw angles critical for both wing-spreading and wing-folding, and also any simple modifications which would offer improvements toward wing-spread operation.

This report presents a correlation between hydraulic pressure and loads in the wing-folding struts over the complete operating range of both wings. The correlation includes a yaw-angle range of from -45° to 30° and a range of tunnel airspeeds from 0 knots to the airspeed at which the upstream wing refused to spread.

Since the time interval necessary for successful wing operation is an important consideration, survey of the time required to fold and spread the wings for various combinations of yaw angle, airspeed, and hydraulic pressure is presented.

Later, tests were conducted on another F4U-1D airplane incorporating modifications made to improve wing-spread operation. These tests involved only the determination of airspeeds and yaw angles critical for wing-spread operation, and time measurements for wing performance.

AIRPLANE AND MODIFICATIONS

The Chance-Vought F4U-1D airplane is a single-place Navy fighter powered by a Pratt and Whitney R-2800-8W engine having a normal take-off rating of 2000 horsepower at 2700 rpm. The airplane was equipped with 8 rocket launchers, 4 on each outer wing panel. With the rockets installed, a favorable weight moment was available for the spreading operation; therefore, for the tests of the original airplane, rockets were mounted only on the downstream wing to simulate maximum loading conditions for the folding operation. Rockets were removed entirely for all tests at 0° yaw and for all tests of the modified airplane. Weights equal to a full ammunition load were installed in the wing ammunition boxes.

A set of modified aileron linkages were installed on the airplane to determine their effect on limiting airspeed for wing-refusal operation. These linkages, which were supplied by the Chance-Vought Company, did not change the aileron control with wings extended, but did produce a $12\frac{1}{2}^{\circ}$ up-aileron deflection (stick neutral) when the wings were folded. An additional 6° up-aileron deflection could be obtained by maximum stick movement toward the folded wing.

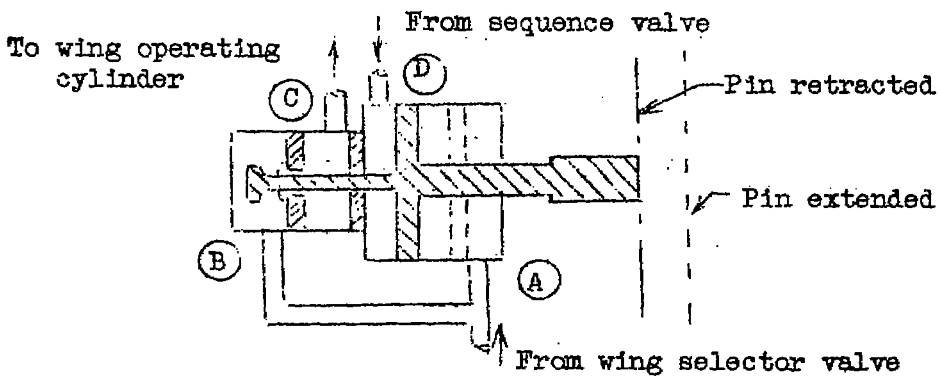
A front-view drawing showing the principal dimensions and wing areas for the airplane is given in figure 1. Photographs of the airplane mounted on the simulated carrier deck in the Langley full-scale tunnel (reference 1) are given in figures 2 and 3.

Original Service Hydraulic System

Oil pressure to operate the wing-folding mechanism is supplied by a Pesco Model 583 DA hydraulic pump. This pump is a gear-type pressure-loaded engine-driven pump having a displacement of 0.555 cubic inch per revolution, a volumetric efficiency of 96 percent, and a maximum continuous operating pressure of 1500 pounds per square inch. It produces a maximum flow of 8.65 gallons per minute at a maximum operating speed of 3750 rpm.

A schematic diagram showing the complete path of oil flow for the airplane hydraulic system is presented in figure 4. A general view showing in part the original service installation of the hydraulic system is shown in figure 5. A description of the original system follows:

First, it should be noted that the oil from the supply tank is circulated through the entire hydraulic system by the above-mentioned pump. In addition to operating the wing-folding unit, this same oil is used to actuate all of the airplane's hydraulic equipment. The oil, after circulating through the pump, first flows through a filter and then directly into an adjustable pressure regulator. This regulator controls the pressure range of the oil in the wing-operating lines. The original service setting of the regulator limits the oil pressure between cut-in and cut-out values of 900^{+50}_{-0} pounds per square inch and 1100^{+50}_{-0} pounds per square inch, respectively. Oil leaving the regulator flows into an accumulator where the pressure energy now present in the system is stored. The accumulator is a sealed spherical tank under a preload air pressure of 400^{+50}_{-0} pounds per square inch. The oil then passes through an adjustable pressure-relief valve. The service setting of this valve is 1250 pounds per square inch cracking pressure. If, for any reason, the oil pressure in the system exceeded the setting of the relief valve, the valve would by-pass enough of the oil to the reservoir to enable the system to return to the preset pressure of the relief valve. At this point in the oil system, the pressure has been properly regulated and the oil enters the wing-operating selector valve located in the cockpit. For the folding operation, the selector valve is placed in the fold position. The oil then passes into the wing-pulling cylinder (installation of this cylinder on the airplane is shown in fig. 6(a)). This cylinder, as sketched below, is used to lock and unlock the outer wing panel in the spread position, and also to control the flow of oil to the folding port of the wing-operating cylinder.



For a folding operation, oil flows into port A and acts to retract the locking pin and unlock the outer wing panel; only after the pin is retracted is oil allowed to flow from port B through a now-open passage into port C and into the folding port of the wing-operating cylinder. This cylinder is mounted in the outer wing panel and, in combination with the mechanical linkage, produces the means for folding and spreading the wings. The cylinder incorporates two ports (folding and spreading), and is equipped with a $3\frac{1}{8}$-inch-diameter double acting piston, and has a displacement from spread to fold of 141.20 cubic inchs and from fold to spread of 122.9 cubic inchs. The difference in displacement is due to a $1\frac{1}{8}$ inch piston rod subtracting from the working area of the piston for the spreading operation. Wing movement is accomplished by transferring the oil pressure acting on the piston into a force in the folding strut. This strut (figs. 6 and 7) is a movable link between the stationary wing center-section horn and the track in the outer wing panel. Oil forced from the wing-operating cylinder during the folding operation is returned to the hydraulic reservoir.

For the spreading operation the flow of oil reverses. The wing-operating selector valve is placed in the spread position and the oil enters a fixed restrictor that restricts both the flow of oil from the wing-operating cylinder during a folding operation, and the flow into the cylinder during spreading. From the restrictor the oil enters the spreading port of the wing-operating cylinder and, in a manner similar to folding, moves the wings into the spread position. The spreading operation differs from the folding in that as the wing assumes the spread position, a sequence valve, shown in figure 6(a), is set into operation and allows the oil to enter port D of the pin-pulling cylinder forcing the locking pin into its extended position. The wing is thus locked and the operation is completed. The sequence valve prevents the wing-hinge pin from extending until the wing has completely spread. As before in the case of the folding operation, the oil forced from the wing-operating cylinder during wing movement is returned to the hydraulic reservoir.

Modified Hydraulic System

The modified hydraulic system, also shown in figure 4, embodies a method of improving the wing-spreading operation by increasing the pressure in only the wing-spread lines. This avoids the possibility of excessive leakage that might result from a pressure increase in the over all systm.

The oil for a spreading operation follows the same path as for the original system with the exception of by-passing the service regulator, the accumulator, and the relief valve. In by-passing the original regulator, the pressure in the spreading lines is controlled solely by a new relief valve set at 1500 pounds per square inch (optional 1800 pounds per square inch) cracking pressure. This boost oil flows through an additional four-way selector valve mounted in the cockpit. The valve has a spring-loaded handle which when released automatically returns the hydraulic system back to the original service condition. By placing the valve in the boost position high-pressure oil is available for spreading the wings. Operation of this valve is required only until the wings have extended past vertical; then it may be released and the system restored to normal.

Further modification was accomplished by replacing the fixed restrictor in the wing-spread line with a one-way restrictor allowing free flow into the spreading port of the wing-operating cylinder and restricting the return flow during folding. This modification made available more pressure in the wing-operating cylinder during spreading but still maintained the precautionary action of preventing damage to the wing tips due to overriding of the end of the folding procedure.

Instrumentation

The instrumentation for the tests of the original airplane included position indicators and strain gages for each wing and a hydraulic pressure gage paralleling the airplane hydraulic pressure indicator. Simultaneous records of the wing positions and pressures were obtained by a flight observer-type camera. Records of the strut loadings as determined from the strain gages were obtained by a recording galvanometer. The strain gage installation is shown in figures 6 and 7. Typical test records of the load variations in the wing-folding struts are shown in figure 8. The actual values accompanying these records are presented in figure 9. An instantaneous record of the hydraulic pressure, the wing position, and the load in the wing-folding struts, was obtained by synchronizing the operation of the flight camera and the recording galvanometer by an electric timer.

An auxiliary valve was installed in the main pressure line in the cockpit forward of the wing-operating selector valve. With this installation it was possible to regulate the wing movement and thus insure accurate measurement of the wing-operating cylinder pressures, for the correlation tests.

No auxiliary instrumentation was required for the tests of the modified airplane, inasmuch as these tests were concerned only with determining limiting airspeeds and time requirements.

PROCEDURES AND TESTS

All the tests were made with the airplane mounted in a three-point attitude on a simulated carrier deck constructed flush with the lower lip of the tunnel entrance cone. The tests closely duplicated carrier operation; since under actual conditions the wind past the wing is a combination of the propeller slipstream and the carrier's speed into the wind.

In order to determine the wing-spread refusal point, the following method for additional boost was performed. First, the control stick was moved toward the inoperative wing in order to raise the aileron on that side and thus, perhaps, provide the actuating force necessary to begin the spreading operation. If this failed to provide the additional boost, then the second procedure was to operate some part of the hydraulic system, such as the cowl flaps, to reduce system pressure below the cut-in (lower) setting of the regulator and to force it to operate at the higher limit of its setting.

The operating time for any specific wing operation is defined as the interval between the operation of the cockpit control and the completion of either the locking or folding of both wings. The simultaneous variations in the hydraulic pressure, wing position, and the load in the wing-folding struts were obtained at half-second time intervals for the complete wing operation.

Tests of the Original Airplane

Tests to determine the limiting airspeeds and the time intervals required for wing operation were made over a yaw range of from -45° to 30° with hydraulic regulator settings of 1100 (service setting), 1350, and 1450 pounds per square inch. An engine speed of 1000 rpm and a main pressure-relief valve setting of 1500 pounds per square inch was maintained for all tests. Tests were also made to determine the effect of modified aileron linkages on limiting airspeed for wing refusal. Conventional service operation prevailed for all of these tests. The limiting airspeed was 50 knots; therefore, refusal conditions and time requirements for airspeeds exceeding 50 knots were undetermined.

Data for the correlation tests to determine the relation between hydraulic pressure and wing-folding strut loading were obtained for the same operating conditions as described for the above-mentioned tests. For this latter series of tests, however, the wings were moved as slowly as possible in order to prevent a pressure loss in hydraulic lines from giving an incorrect pressure recording.

Tests were also performed to determine if sufficient hydraulic pressure was available to pull the wing-locking pins at airspeeds of at least 50 knots with the airplane at 0° yaw and with all ammunition and rockets removed from the wing.

Tests of Modified Airplane

These tests were conducted to determine the improvement resulting from modifying the hydraulic system. Tests were made at 0°, -30°, and -40° yaw position for airspeeds ranging from an airspeed below where operation was assured (by previous tests on the original airplane) to the higher refusal limit. The tests were limited to a maximum airspeed of 70 knots. Engine speeds of both 1000 and 1500 rpm and special regulator by-pass pressures of 1500 and 1800 pounds per square inch were tested for each yaw and airspeed.

RESULTS AND DISCUSSION

The data are presented in graphical form by composite plots showing the variations of hydraulic pressure and wing-folding strut loads with changing angle of wing rotation for a range-of-yaw positions and test airspeeds. The time intervals required for wing operation, and the airspeeds at which wing-spread refusal occurred are presented in tabular form for the original and the modified airplanes.

Inasmuch as data were not obtained for all combinations of regular settings and types of linkages at all the yaw positions tested, there are some variations of test conditions given in the correlation plots. Any such variation of test conditions would have no material effect upon the correlation results presented herein.

The test results and analysis of the data are divided into two sections. The first section, entitled "Wing-Operating Characteristics" gives results showing the airspeeds and yaw angles critical for wing operation, and the time intervals required for wing performance at airspeeds up to the wing refusal points. The second section, "Correlation Results," presents a correlation between the hydraulic pressure and the loads in the wing-folding struts over the complete operating range of both wings.

Wing-Operating Characteristics

Limiting airspeeds.- The most critical condition for wing operation would conceivably occur when attempting to spread the upstream wing with the airplane at 90° yaw. The critical condition aboard an aircraft carrier from the standpoint of space-saving and safety, however, would be in the vicinity of a ±45° angle of yaw.

The data given in table I(A) for the original airplane show that wing-spread operation at airspeeds of 50+ knots was obtained at yaw positions up to and including ±10° yaw for the three regulator settings tested and for both aileron linkage installations. At -30° and -45° yaw, wing-refusal operation with pressure-regulator setting of 1450 pounds per square inch occurred at 40.5 knots and 45.0 knots, respectively. It can be concluded that for the yaw range covered in these tests, the 30° yaw position was the most severe condition when considering limiting airspeeds for wing-spread operation.

In general, the installation of the modified aileron linkages was beneficial for increasing the limits for wing-spread refusal. The greatest gain obtained was a 10-knot increase in airspeed at the -30° yaw.

The results of the modified airplane, incorporating the special regulator by-pass system, as presented in table I(B) show that at 0° angle of yaw, wing operation was obtained at an airspeed of 70 knots for a boost pressure of 1800 pounds per square inch. At the -30° yaw position, an increase in boost pressure from 1500 to 1800 pounds per square inch increased the limiting airspeed from 49 to 54 knots. These same limits were obtained for the -40° angle of yaw. Increasing the engine speed from 1000 to 1500 rpm and, consequently, increasing the oil flow produced no change in the wing-spread refusal points over the yaw range tested.

Time requirements.- The time intervals required for the original airplane at each angle of yaw for the maximum airspeeds at which wing operation was obtained are presented in table II(A).

In general, conventional wing operation (spread and fold) was performed for all test configurations in approximately 30 seconds or less. The operating time necessarily increased whenever the aid of the cockpit operational procedures was required; in table II(A) for the yaw positions of 15° and 20°, wing-spread operation required additional aid and was performed in 52.5 and 66.0 seconds, respectively. Data for the 0° yaw show that an increase in pressure or airspeed had very little effect upon operating time.

The results of the tests on the modified airplane are given in table II(B). Inasmuch as the boost pressure produced with the modified system is not available for the folding operation, the results show only the effect of the modified system upon wing-spread time.

The spreading time averaged approximately 20 seconds, and was not appreciably changed over the range of airspeeds and angles of yaw tested. A complete comparison cannot be made of the time required for wing operation of the modified and original airplanes, because the results for the modified airplane are for the most part at airspeeds surpassing those possible with the original installation. The results in general show that the spreading operation was performed in less time at the higher airspeeds with the 1800 pounds per square inch pressure than was possible at the lower airspeeds with the 1100 pounds per square inch pressure.

Increasing the engine speed from 1000 to 1500 rpm consequently increases the oil flow in the hydraulic system and also the slipstream velocity. This increase in engine speed decreased the folding time in some cases by as much as 15 seconds and the spreading time by as much as from 3 to 6 seconds.

For wing-folding, the wings do not enter the region of propeller slipstream until they have moved beyond the vertical; therefore, any increase in propeller slipstream velocity appears to have very little effect on the folding time in relation to the benefits obtained from the greater oil flow.

For the spreading operation, however, the wing in the full-folded position appears to be located in the region of the flow from the propeller. This flow over the wing evidently produces a lift component inward in the direction of the fuselage. Any increase in engine speed, therefore, would produce an increased force opposing the outward movement of the wing. To overcome this adverse effect at the start of the wing-spread maneuver, a successful technique was employed whereby the engine was first idled until the wing moved beyond vertical and then the speed was increased for the remainder of the operation.

Wing-locking effectiveness.- Visual observation of the wing-locking operation showed that there was sufficient hydraulic pressure available with service regulator setting of 1100 pounds per square inch to pull the wing-locking pins at an airspeed of at least 50 knots with the airplane at 0° yaw and all ammunition and rockets removed from the wing. Furthermore, no difficulty was encountered with the wing-locking operation for the entire yaw range and airspeeds tested.

Correlation Results

Static variation of load in wing-folding strut with wing position.- A fundamental explanation of load variation in the wing-actuating strut with changing wing position under static conditions is given in the following paragraphs. (The actual mechanics involved in achieving wing movement have been explained previously in the description of the original hydraulic system.)

At the start of a folding operation, the action of the oil against the outward face of the operating piston produces a compression load in the wing-folding strut. The load remains a compression value until the wing folds beyond vertical whereupon it reverses to a tension value. This load occurs since the oil in the operating cylinder for wing movement from vertical to full-folded position is acting to retard the free fall of the wing in the direction of the fuselage.

Actual values of the static loadings present in the folding struts have been calculated from the weight data provided by Chance-Vought Aircraft.

These data are presented in the following table:

Outer Wing Panel Weight and Center of Gravity Locations			
Weight conditions	Weight (lb)	Horizontal Arm from C_L airplane (in.)	Horizontal arm from wing hinge (in.)
(1) Panel 3 guns	777.0	126.5	38.4
(2) Condition (1) 1200 rounds ammunition	1135.8	130.8	42.7

Note: Vertical arms for conditions (1) and (2) are on rib chord line, approximately 6 inches below upper wing surface.

In order to determine the static loading in the folding strut it was necessary to ascertain the effective lever arm of the wing-folding strut. The variation of effective arm with wing position was supplied by Chance-Vought Aircraft and is presented with a schematic diagram in figure 10. The known outer-panel weight moment as determined from the information in the above table was divided by this effective arm and the resulting loadings for the range in wing positions are plotted in figure 11. The most severe static loadings are shown to occur during the wing-folding operation, since the static loads for the start of folding are nearly three times as great as those present for the start of the spreading operation.

Pressure evaluation for wing-spread operation.- Under conditions of carrier operation, however, the most severe loading condition in the actuating strut will occur for the spreading of the upstream wing because of the addition to the static loads of the air loads due to airspeed and yaw. A three-dimensional variation of average load in the actuating strut of the folded upstream wing with angle of yaw and airspeed is shown in figure 12. This figure was constructed from a standard two-dimensional plot of average loads in the actuating strut (wing folded) against angle of yaw for the range of airspeeds tested. Data used in this construction was obtained from test results of the original airplane. The values presented in figure 12 represent an average of the loads present throughout the entire time interval while the upstream wing remained in the folded position and do not necessarily agree exactly with the instantaneous values presented for the same wing position in the correlation (figs. 13 through 21).

The approximate pressure required for performing a spreading operation up to and beyond the refusal limits determined from the tests of the original airplane may be computed from the values of the loads given in figure 12. This approximation requires a knowledge of only the angular relationship between the actuating strut and the piston rod (wing folded), and the area of the operating piston. All rockets are removed from the upstream wing and pressure values are those present in the operating cylinder and do not include line pressure loss. The effective hydraulic cylinder piston area is 6.67 square inches and the angle between the actuating strut and piston rod extended (wing folded) is approximately 37°.

It has been found that wing-spread operation was unobtainable with the original airplane at 30° angle of yaw and an airspeed of 50 knots. Figure 12 shows that for these conditions an estimated load of 14,500 pounds would be present in the actuating strut.

The cylinder hydraulic pressure required to overcome this loading is computed to be

$$\frac{14,500 \ (\cos 37^{\circ})}{6.67} \approx 1740 \text{ psi}$$

This value shows good agreement with the limiting airspeeds for the modified airplane where wing-spread refusal at similar yaw occurred at 49 knots with a pressure of 1500 pounds per square inch and at 54 knots with 1800 pounds per square inch, indicating that operation at 50 knots would require a pressure somewhere between the above two values.

Effect of yaw and airspeed on pressure-load variation with wing position.- Composite plots showing the actual variation of hydraulic pressure and load in the wing-folding struts with wing position for the folding and spreading operation are presented in figures 13 through 21.

In general, from the standpoint of critical airspeeds, the pressure-load data for folding are not of great importance since wing-refusal operation occurred only when attempting to spread the wings.

The discussion of the pressure-load trends can be conveniently classified under the following groups:

(1) Folding the upstream wing

(2) Folding the downstream wing

(3) Spreading the upstream wing

(4) Spreading the downstream wing

(1) The air stream aids the folding operation of the upstream wing, causing it to fold first. For all yaw positions tested, maximum pressure occurred at the beginning of the operation and decreased rapidly with upward wing movement as more of the wing's surface was exposed to the lifting action of the air stream. This action was more pronounced at the higher yaw angles.

The loads at the start of the operation showed a trend toward lower compression values with increase in airspeed; however, considerable increase in tension load values occurred as a result of the greater retarding action required in stopping the wings. Figures 14(a), 15(a), and 18(a) show examples at high airspeeds where the loads were entirely tension values, indicating that wing movement was accomplished without the aid of oil pressure.

(2) In general, with airplane yawed, the air stream retards the folding operation of the downstream wing. A comparison of the pressure results at variable airspeeds with those at zero airspeed shows that, with the exception of zero yaw, the folding operation required less pressure at higher airspeeds until the wing reached a certain position. This reduction of pressure resulted from more favorable aerodynamic loading with increase in airspeed; but, for wing movement beyond the above mentioned point, the aerodynamic loading reversed and caused a pressure increase over that required for static operation. This aerodynamic characteristic likewise appeared in the load results of the wing-actuating strut. Figure 13(a) shows that, for 30° yaw, this reversal of aerodynamic loading occurred when the wing reached a position approximately 40° from the horizontal. The reversal appeared at lower wing positions for the higher yaw angles. As yaw decreased, the wing appeared to retain its lifting power for successively higher wing positions; at 0° yaw, the wind apparently aided the entire folding operation.

(3) The effect of wind on the spreading of the upstream wing has previously been shown in figure 12, where the load necessary to start wing spread increased rapidly with increase in airspeed and yaw angle. Maximum pressure for all yaw positions was required to start wing spread and successively greater starting pressures were required as airspeed increased. Wing operation, after the wing moved beyond vertical, was aided by the downward weight-moment of the wing and, consequently, required less pressure. Figures 14(b) and 15(b) show results where wing operation required the action of the pressure regulator. The pressure and load values given in all cases for refusal operation were the maximum values obtained in attempting to spread the wing.

(4) The spreading of the downstream wing with the exception of the 0° yaw position was performed almost entirely by the action of the wind. At 0° yaw (fig. 17(b)) the spreading operation required the lowest pressure values for zero airspeed; as airspeed was increased, the pressure likewise increased in order to overcome the upward lift components present in the wing during the entire spreading operation.

CONCLUDING REMARKS

Additional methods believed possible for improving wing spreading are presented as follows:

(a) Mechanically or hydraulically prevent the wings from folding beyond vertical, except by a special release mechanism to be used when a full-folded condition would be advantageous. In spreading the wings from the vertical, the strut loading would be greatly decreased; the magnitude would depend upon the yaw and airspeed under which the wing operation would be performed.

(b) Increase the mechanical advantage of the wing-spread linkage.

(c) Increase the diameter of the actuating cylinder and strengthen the actuating mechanism.

SUMMARY OF RESULTS

Data are presented of tests made in the Langley full-scale tunnel on the Chance-Vought F4U-1D airplane to investigate its wing-operating characteristics. Although these data pertain particularly to this airplane, the trends and limits are believed to be applicable to other aircraft having somewhat similar folding characteristics.

The results of the tests may be summarized as follows:

1. Wing-spread operation under original service conditions was obtained at airspeeds of 50+ knots for yaw positions up to and including $\pm 10^{\circ}$ yaw. The 30° yaw position was the most severe condition when considering limiting airspeeds. Increasing the hydraulic pressure to 1800 pounds per square inch, as was the case with the modified airplane, permitted wing operation at 70+ knots for 0° yaw and increased the limiting airspeed to 54 knots with airplane yawed -40°. The wing-folding characteristics were satisfactory for all conditions tested.

2. Increase in propeller slipstream had little effect on the folding time in relation to the benefits obtained from the resulting greater oil flow. The spreading operation, however, was importantly influenced by increase in propeller slipstream. It was determined that, for increased engine speed to prove effective in decreasing spreading time, the engine should first be idled until the wing moves beyond vertical and then increased for the remainder of the operation.

3. In general, the installation of the modified aileron linkages was beneficial for increasing the limits for wing-spread refusal. The greatest gain obtained was a 10-knot increase in airspeed at the -30° yaw.

4. The action of the wing pin-pulling cylinder provided successful wing-locking and wing-unlocking operation over the entire yaw range and airspeeds tested.

5. The method formulated for exaluation of the pressure required up to and beyond wing-spread-refusal conditions showed good agreement with actual test values.

6. Folding.- In general, the relative wind with airplane yawed aided the folding of the upstream wing and retarded the folding of the downstream wing. Definite adverse aerodynamic characteristics occurred in folding the downstream wing. At 0° yaw, the air flow aided the entire folding operation as the lifting forces were always in the desired direction of wing movement.

Spreading.- The spreading of the downstream wing with the exception of the 0° yaw position was performed almost entirely by the action of the tunnel airflow. The adverse wind effect on the spreading of the upstream wing increased rapidly with increase in airspeed and yaw angle. Maximum pressure requirement occurs in attempting to spread the upstream wing. At 0° yaw, the tunnel air flow retarded the spreading of both wings.

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REFERENCE

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TABLE I

LIMITING AIRSPEEDS FOR WING-SPREAD

OPERATION OF THE F4U-1D AIRPLANE

(A) Original Airplane

[Full ammunition load in both wings, rockets installed only on downstream wing, rockets off at 0° yaw, main relief valve set at 1500 pounds per square inch]

Angle of yaw, (Positive, nose right) (deg)	Regulator pressure (psi)	Engine speed (rpm)	Limiting indicated airspeed, knots aileron linkage	
			Original	Modified
-45	1100	1000	(a)	(a)
	1350		40.5	45.0
	1450		45.0	45.0
-30	1100	1000	(a)	(a)
	1350		40.5	50.0
	1450		40.5	50.0
-20	1100	1000	(a)	(a)
	1350		45.0	(a)
	1450		45.0	(a)
-10	1100	1000	50	50+
	1350		50	50+
	1450		50	50+
0	1100	1000	50	50+
	1350		50	50+
	1450		50	50+
10	1100	1000	50	50+
	1350		50	50+
	1450		50	50+
15	1100	1000	40.5	(a)
	1350		50.0	50+
	1450		50.0	50+
20	1100	1000	35.6	40.5
	1350		45.0	45.0
	1450		50.0	50.0
30	1100	1000	35.6	(a)
	1350		40.5	(a)
	1450		40.5	(a)

(a) Data were not obtained for this condition.

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TABLE I

LIMITING AIRSPEEDS - Concluded

(B) Modified Airplane

[Full ammunition load in both wings, rockets off, original aileron linkages]

Angle of yaw (deg)	Wing-spread regulator, by-pass pressure (psi)	Engine speed (rpm)	Limiting indicated airspeed (knots)
0	1500	1000	57+
	1500	1500	57+
	1800	1000	70+
	1800	1500	70+
-30	1500	1000	49.0
	1500	1500	49.0
	1800	1000	54.0
-40	1500	1000	49.0
	1800	1000	54.0
	1800	1500	54.0

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TABLE II

TIME REQUIRED FOR WING OPERATION

OF THE F4U-1D AIRPLANE

(A) Original Airplane

[Full ammunition load in both wings, rockets installed only on downstream wing, rockets off at 0° yaw, main relief valve, 1500 pounds per square inch]

Angle of yaw (deg)	Regulator pressure (psi)	Engine (rpm)	Indicated airspeed (knots)	Wing-operating time (sec)	
				Fold	Spread
-45	1450	1000	40.5	33.5	27.5
-30	1450	1000	35.6	29.5	24.0
-20	1450	1000	40.5	28.0	25.5
-10	1450	1000	50.0	25.5	23.0
0	1100	1000	45.0	20.5	20.5
	1100	1000	50.0	20.0	21.5
	1350	1000	45.0	20.5	20.0
	1350	1000	50.0	21.0	20.0
	1450	1000	45.0	19.0	18.5
0	1450	1000	50.0	21.0	19.0
10	1450	1000	50.0	25.5	25.5
15	1450	1000	50.0	27.5	52.5
20	1450	1000	45.0	26.0	66.0
30	1450	1000	35.6	27.0	24.0

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TABLE II

TIME REQUIRED FOR WING-OPERATION - Concluded

(B) Modified Airplane

[Full ammunition load in both wings, rockets off, original aileron linkage]

Angle of yaw, (deg)	Wing-spread regulator by-pass pressure	Engine speed, (rpm)	Indicated airspeed, (knots)	Wing-operating time (sec)	
				Fold	Spread
0	1500	1000	54.0	21.5	21.0
		1500	54.0	15.5	16.0
		1000	57.0	21.0	21.0
	1500	1500	57.0	15.5	17.5
	1800	1000	61.0	----	23.0
		1500	61.0	15.0	15.0
		1000	63.0	20.0	22.5
		1500	63.0	15.0	15.0
		1000	66.0	19.0	22.0
		1500	66.0	14.5	14.5
		1000	70.0	----	22.0
0	1800	1500	70.0	15.0	15.5
-30	1500	1000	39.0	32.0	21.5
	1500	1500	39.0	22.5	15.0
	1800	1000	43.0	31.0	18.0
		1500	43.0	24.0	15.0
		1000	49.0	33.5	21.0
		1500	49.0	24.0	17.0
		1000	51.0	33.0	23.0
-30	1800	1500	51.0	24.0	24.0
-40	1800	1000	49.0	38.0	20.0
		1500	49.0	30.0	15.0
		1000	51.0	45.0	20.0
-40	1800	1500	51.0	30.0	16.0

Note: Boost pressure available only for spreading.

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FIGURE LEGENDS

Figure 1.- Front-view drawing of F4U-1D airplane.

Figure 2.- The F4U-1D airplane at 0° yaw in the Langley full-scale tunnel.

(a) Front view.

Figure 2.- Concluded.

(b) Side view.

Figure 3.- The F4U-1D airplane at -45° yaw.

(a) Top view, wings shown in spread position.

Figure 3.- Concluded.

(b) Top view, wings shown in folded position.

Figure 4.- Schematic diagram of original and modified hydraulic system - F4U-1D airplane.

Figure 5.- General view showing in part the service installation of the F4U-1D airplane hydraulic system directly aft of the engine.

Figure 6.- Wing-operating mechanism of the F4U-1D airplane; wing in the folded position.

Figure 7.- Detail view of the wing-folding strut with strain gage installed. F4U-1D airplane.

Figure 8.- Typical test records of the load variations in the wing-folding struts - F4U-1D airplane.

Figure 9.- Actual values showing both the load variations in the wing-folding struts for the typical test records presented in figure 8, and also the variation of the hydraulic pressure and wing position with time for the same test conditions. F4U-1D airplane.

(a) Typical folding operation (Test record 1): 20° yaw, 33 knots, 1100 psi regulator setting, rockets on downstream wing only, full ammunition load, original aileron linkages.

FIGURE LEGENDS - Continued

Figure 9.- Continued.

(b) Typical spreading operation (Test record 2): 20° yaw, 33 knots, 1100 psi regulator setting, rockets on downstream wing only, full ammunition load, original aileron linkages.

Figure 9.- Continued.

(c) Typical spreading operation (Test record 3): 20° yaw, 35.6 knots, 1100 psi regulator setting, rockets on downstream wing only, full ammunition load, original aileron linkages.

Figure 9.- Continued.

(d) Typical folding operation (Test record 4): 0° yaw, 45 knots, 1450 psi regulator setting, rockets removed, full ammunition load, modified aileron linkages.

Figure 9.- Concluded.

(e) Typical spreading operation (Test record 5): 0° yaw, 45 knots, 1450 psi regulator setting, rockets removed, full ammunition load, modified aileron linkages.

Figure 10.- Variation of effective arm with wing position. F4U-1D airplane.

Figure 11.- Variation of approximate static load in wing-folding strut with wing position. F4U-1D airplane.

Figure 12.- Variation with angle of yaw and airspeed of the average load in the folding strut of the upstream wing at the start of the spreading operation. F4U-1D airplane.

Figure 13.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 30° yaw; 1450 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 13.- Concluded.

(b) Spreading operation.

FIGURE LEGENDS - Continued

Figure 14.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 20° yaw; 1450 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 14.- Concluded.

(b) Spreading operation.

Figure 15.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 15° yaw; 1450 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. FrU-1D airplane.

(a) Folding operation.

Figure 15.- Concluded.

(b) Spreading operation.

Figure 16.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 10° yaw; 1350 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 16.- Concluded.

(b) Spreading operation.

Figure 17.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 0° yaw; 1450 psi regulator setting, modified aileron linkages, rockets removed, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 17.- Concluded.

(b) Spreading operation.

FIGURE LEGENDS - Concluded

Figure 18.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -10° yaw; 1350 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 18.- Concluded.

(b) Spreading operation.

Figure 19.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -20° yaw; 1350 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 19.- Concluded.

(b) Spreading operation.

Figure 20.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -30° yaw; 1350 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 20.- Concluded.

(b) Spreading operation.

Figure 21.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -45° yaw; 1350 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

(a) Folding operation.

Figure 21.- Concluded.

(b) Spreading operation.

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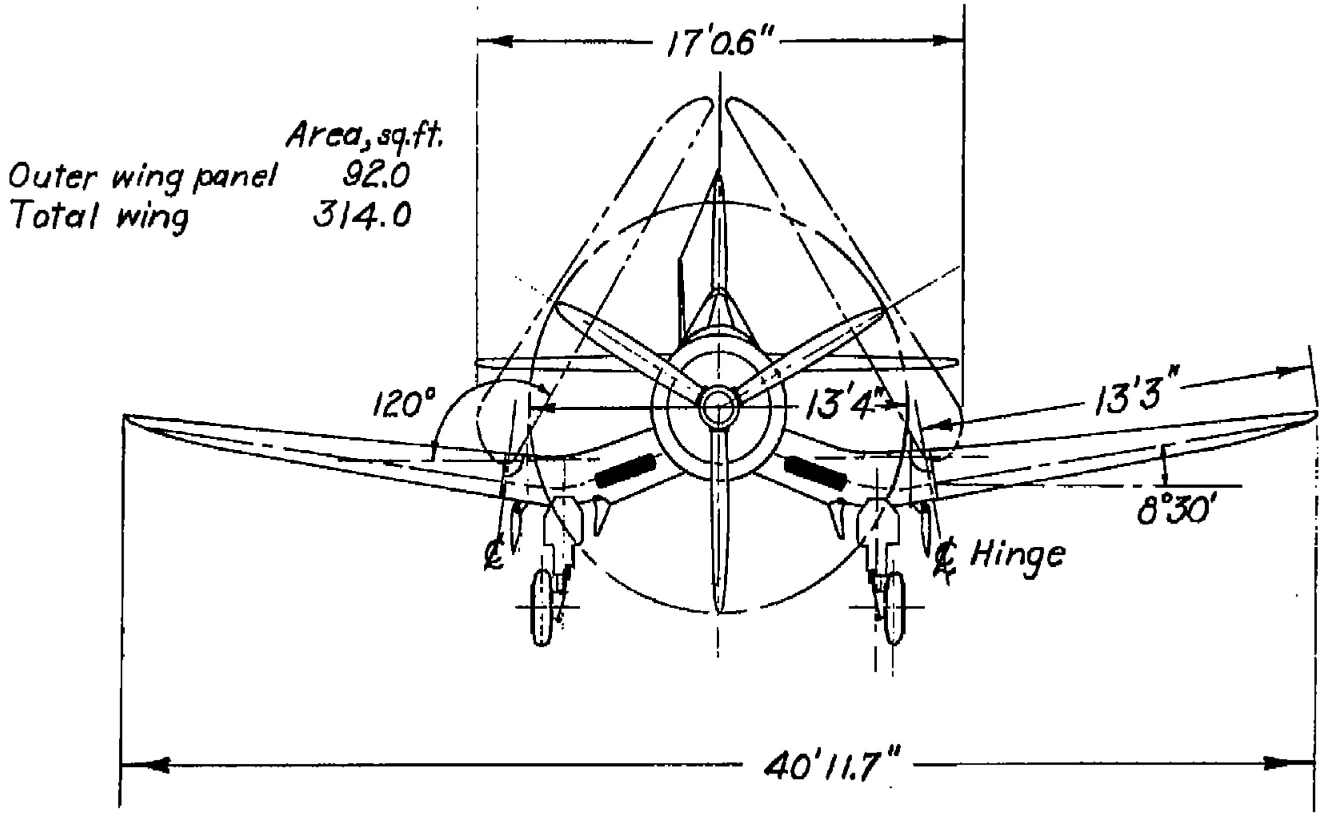

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Figure 1.- Front-view drawing of F4U-1D airplane.

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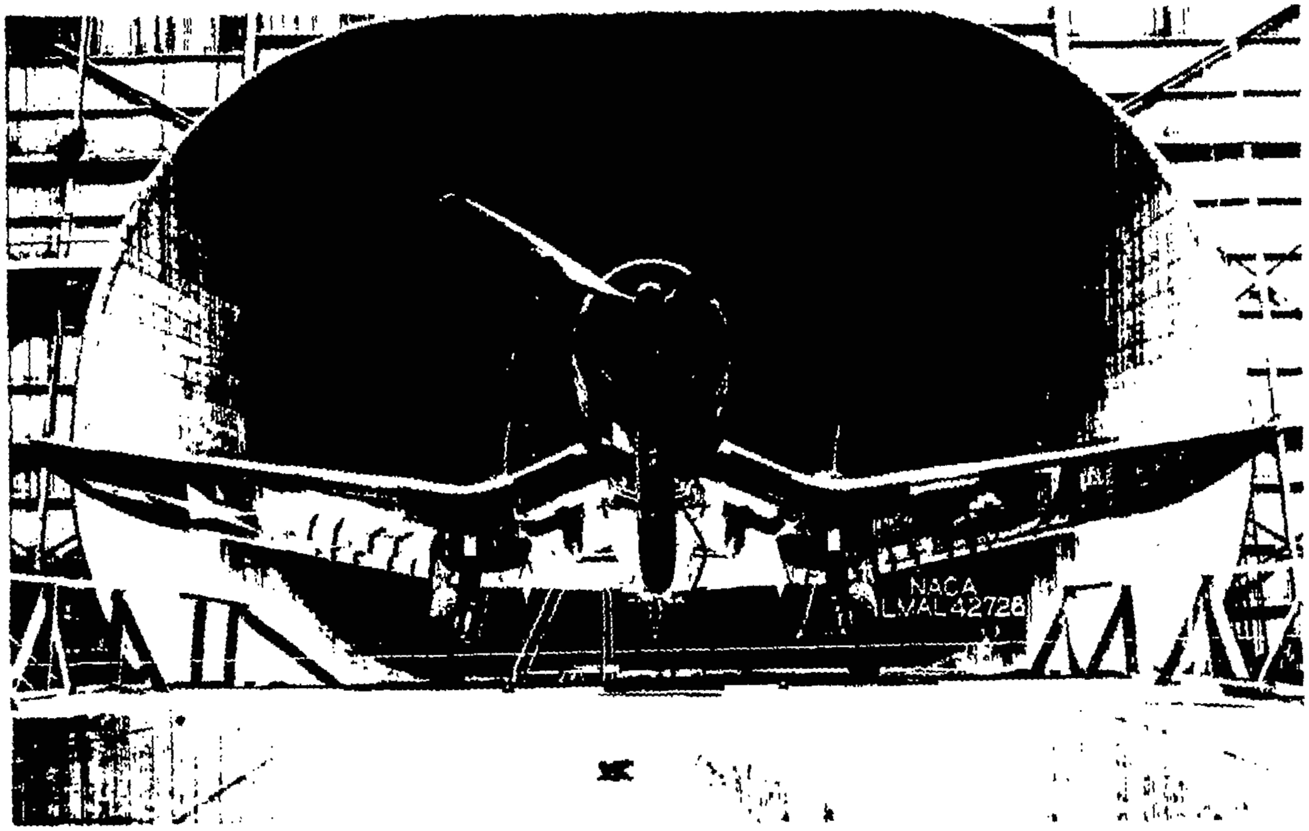

(a) Front view.

Figure 2.- The F4U-1D airplane at 0° yaw in the Langley full-scale tunnel.

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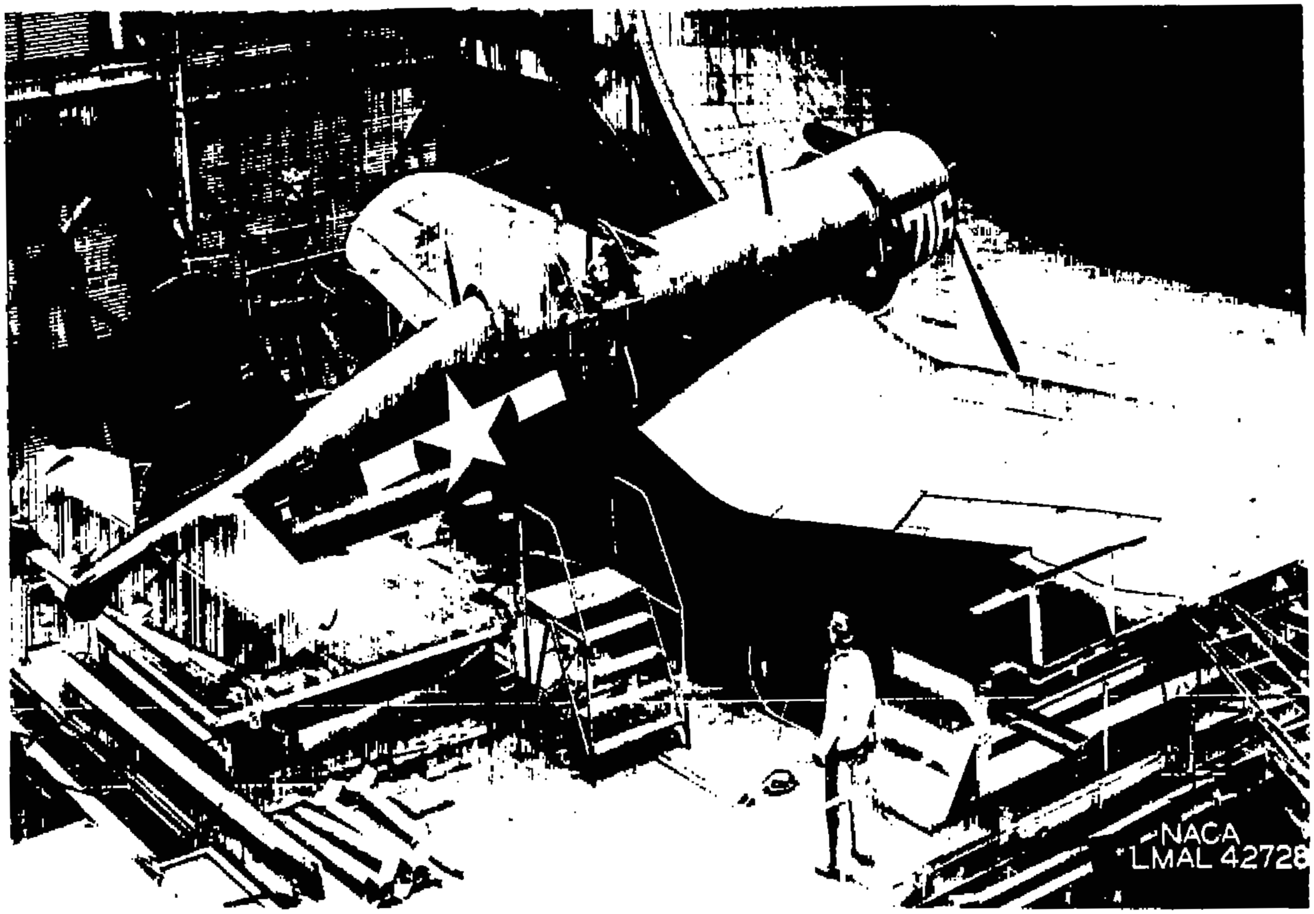

(b) Side view.

Figure 2.- Concluded.

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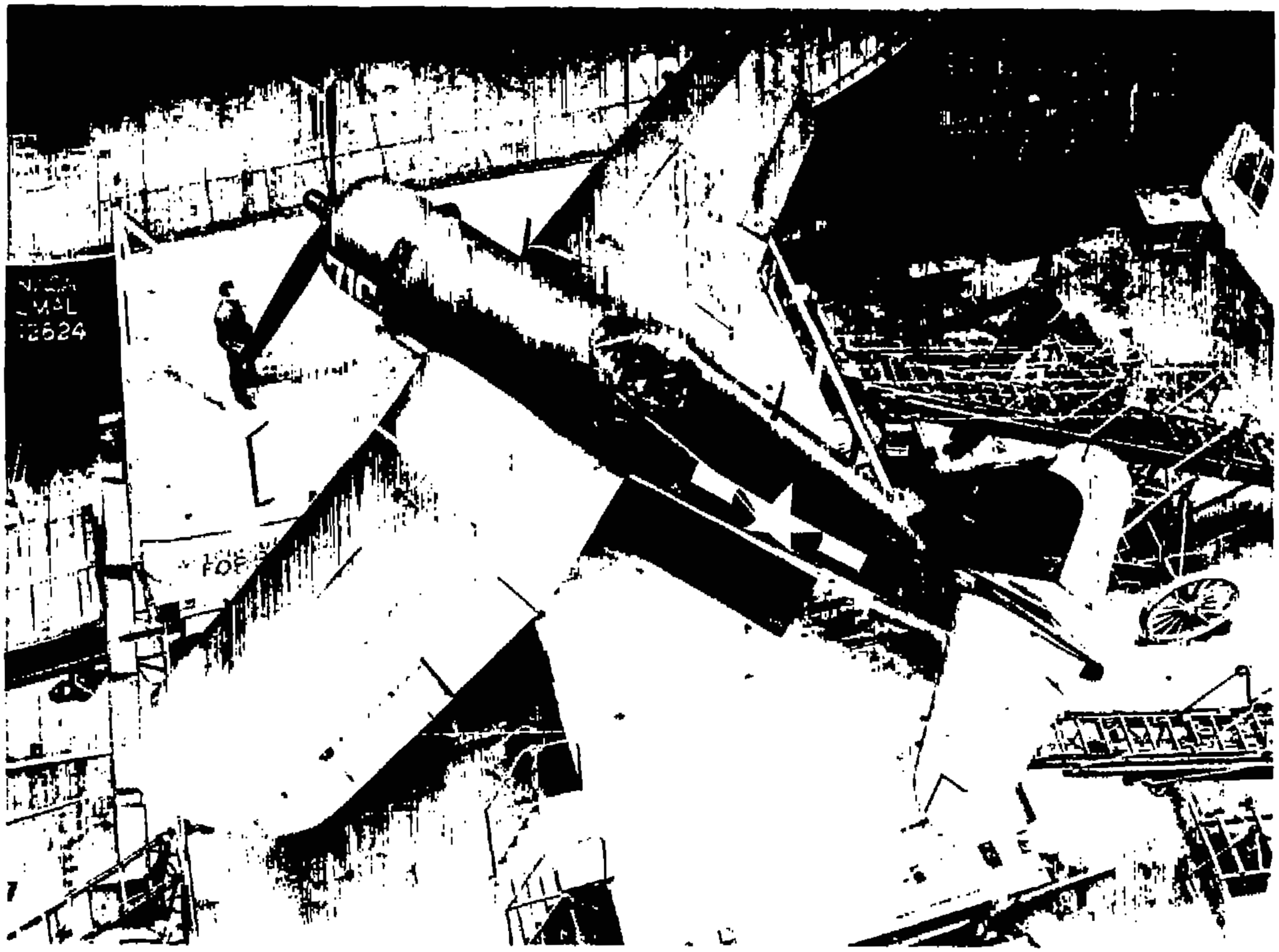

(a) Top view, wings shown in spread position.

Figure 3.- The F4U-1D airplane at -45° yaw.

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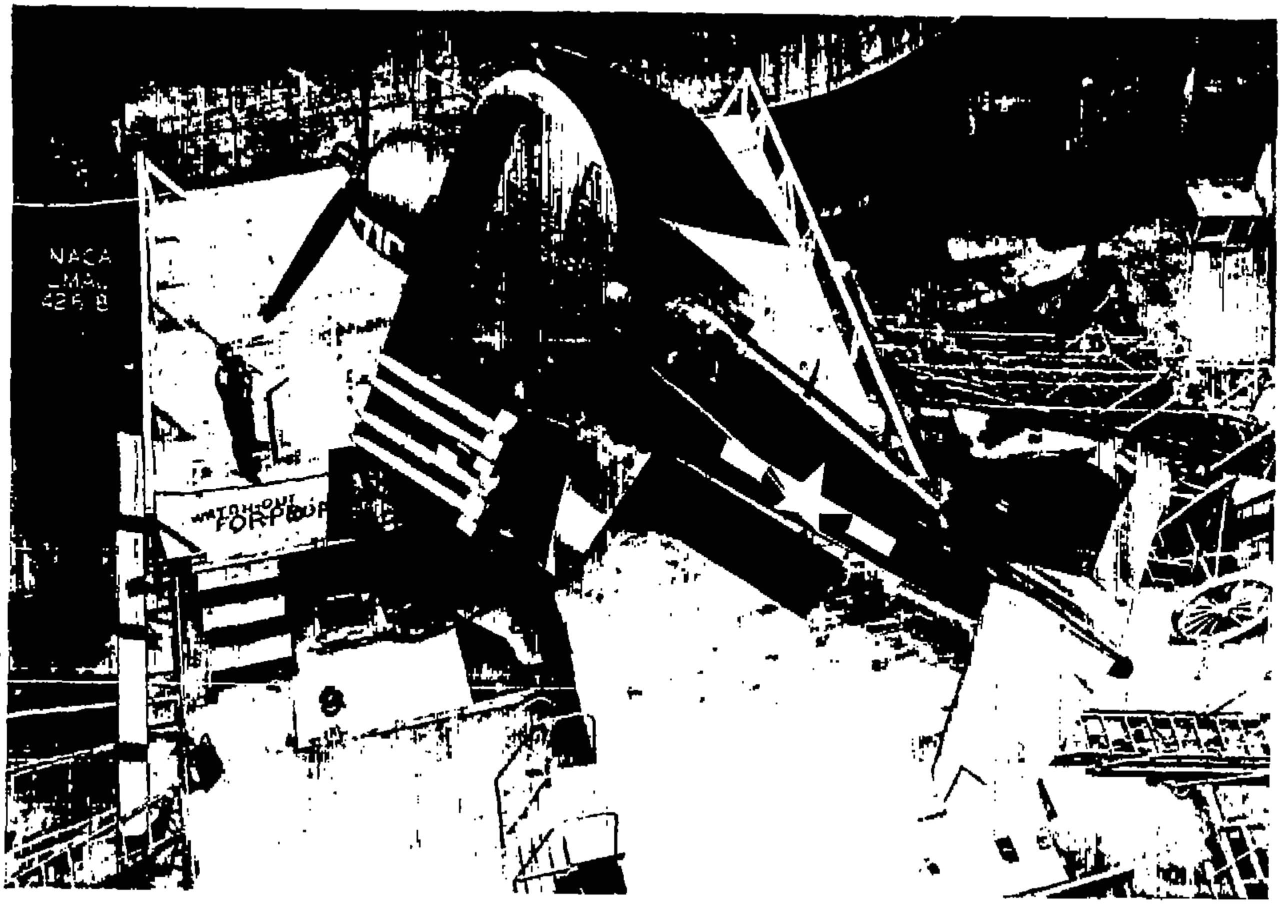

(b) Top view, wings shown in folded position.

Figure 3.- Concluded.

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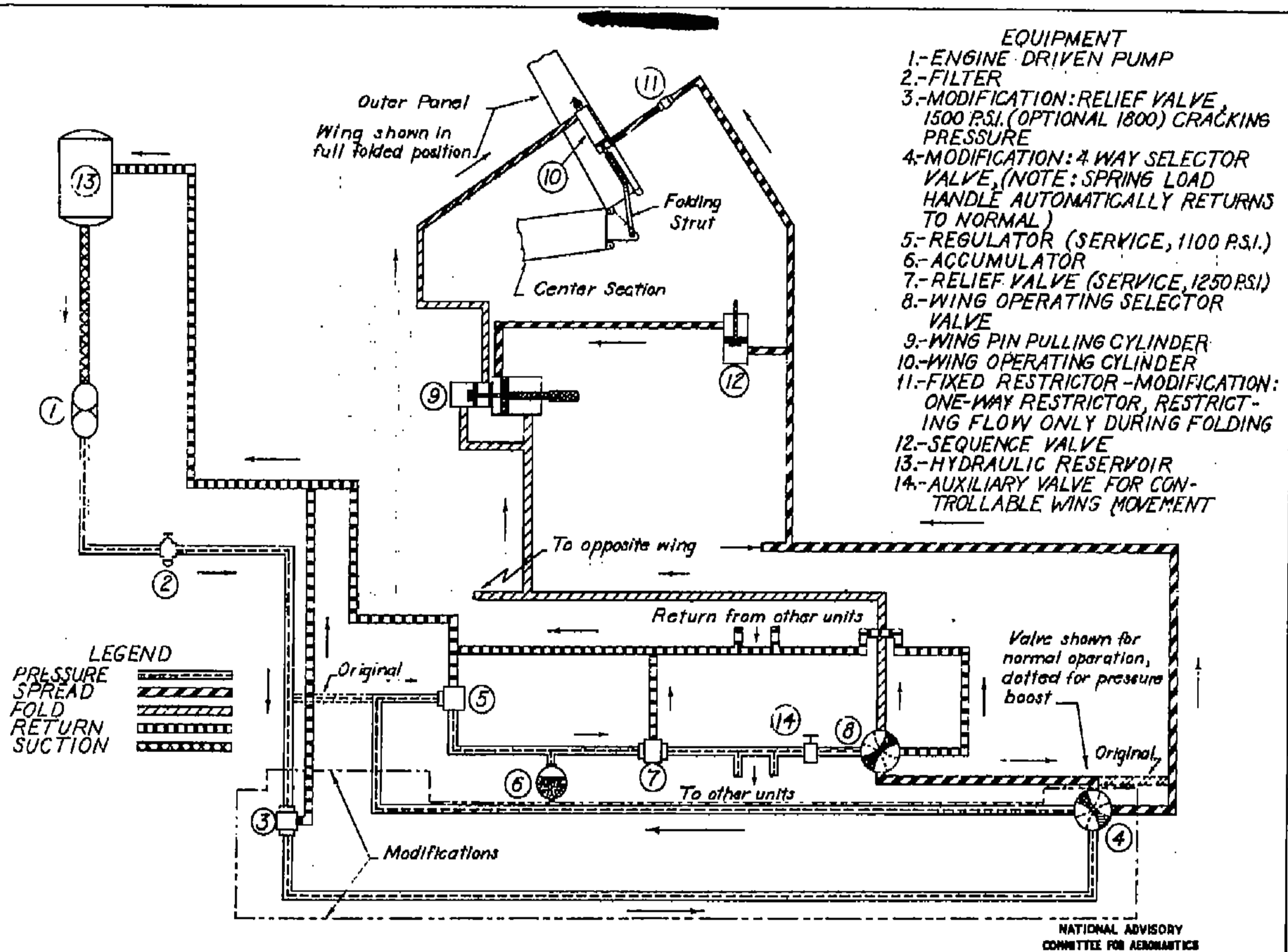

Figure 4.-Schematic diagram of original and modified hydraulic system.- F4U-1D airplane

Arrows indicate direction of flow

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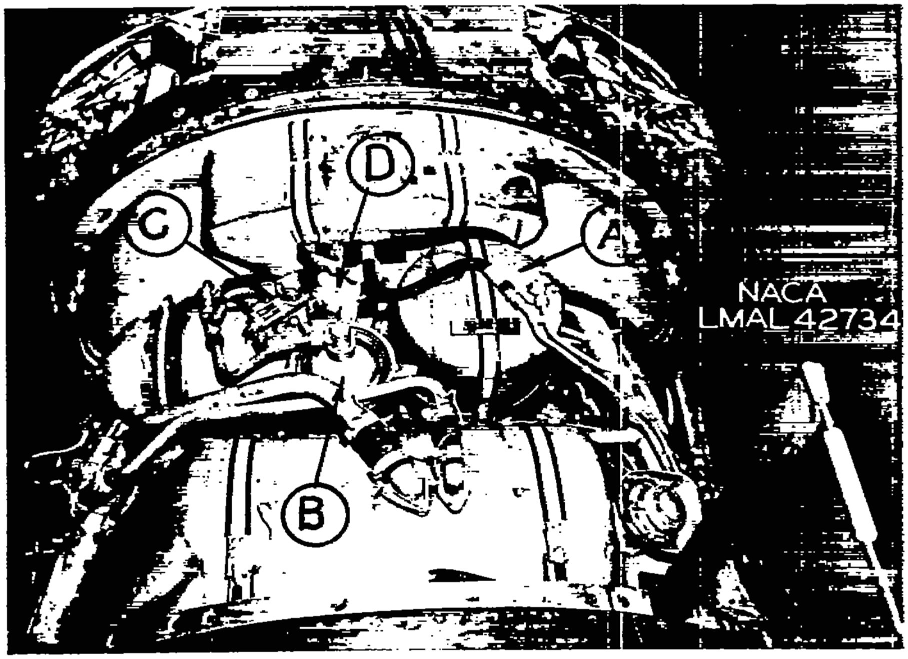

A Hydraulic reservoir

B Accumulator

C Regulator

D Filter

Figure 5.- General view showing in part the service installation of the F4U-1D airplane hydraulic system directly aft of the engine.

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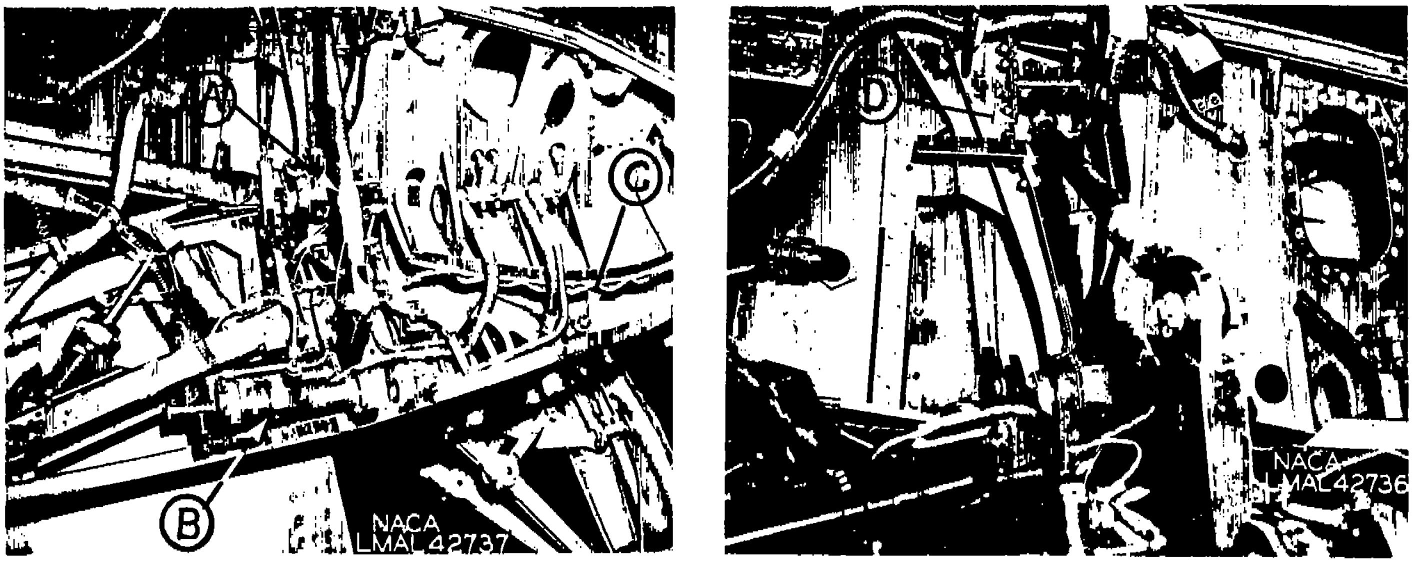

(a) View showing folding strut and strain gage installation A , pin-pulling cylinder B , sequence valve C .

(b) View showing folding strut and track installation in the outer wing panel D .

Figure 6.- Wing-operating mechanism of the F4U-1D airplane; wing in the folded position.

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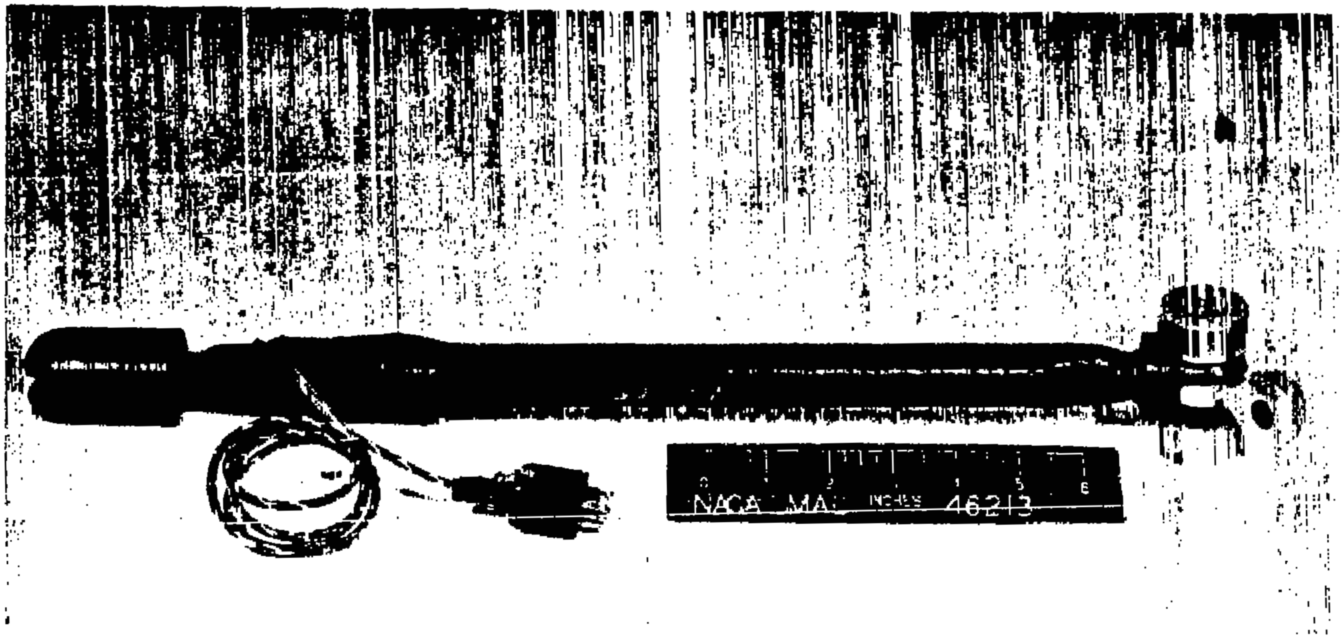

Figure 7.- Detail view of the wing-folding strut with strain gage installed.
F4U-1D airplane.

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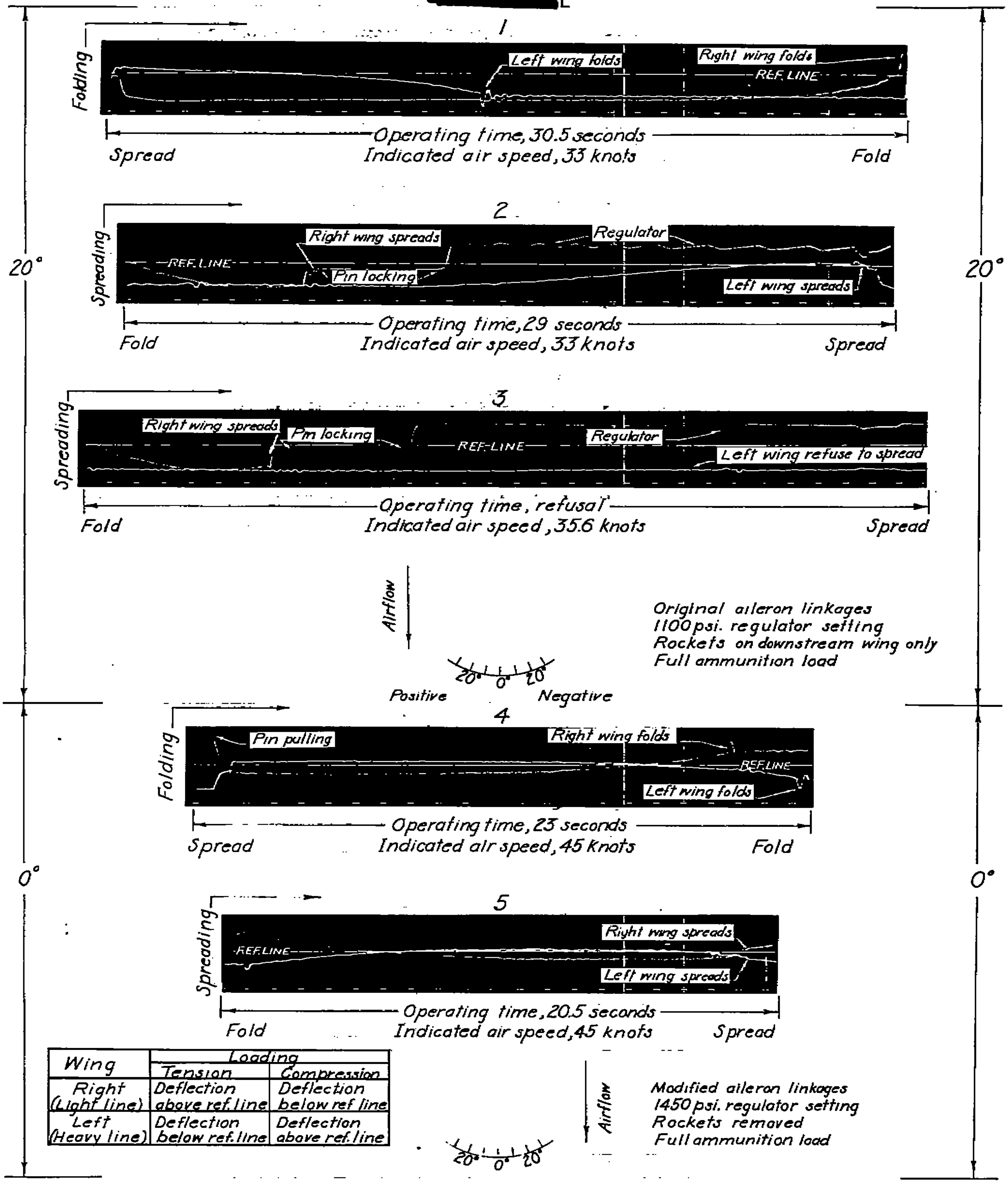

Wing	Loading	
	Tension	Compression
Right (Light line)	Deflection above ref. line	Deflection below ref. line
Left (Heavy line)	Deflection below ref. line	Deflection above ref. line

Figure 8.- Typical test records of the load variations in the wing-folding struts. - F4U-1D airplane

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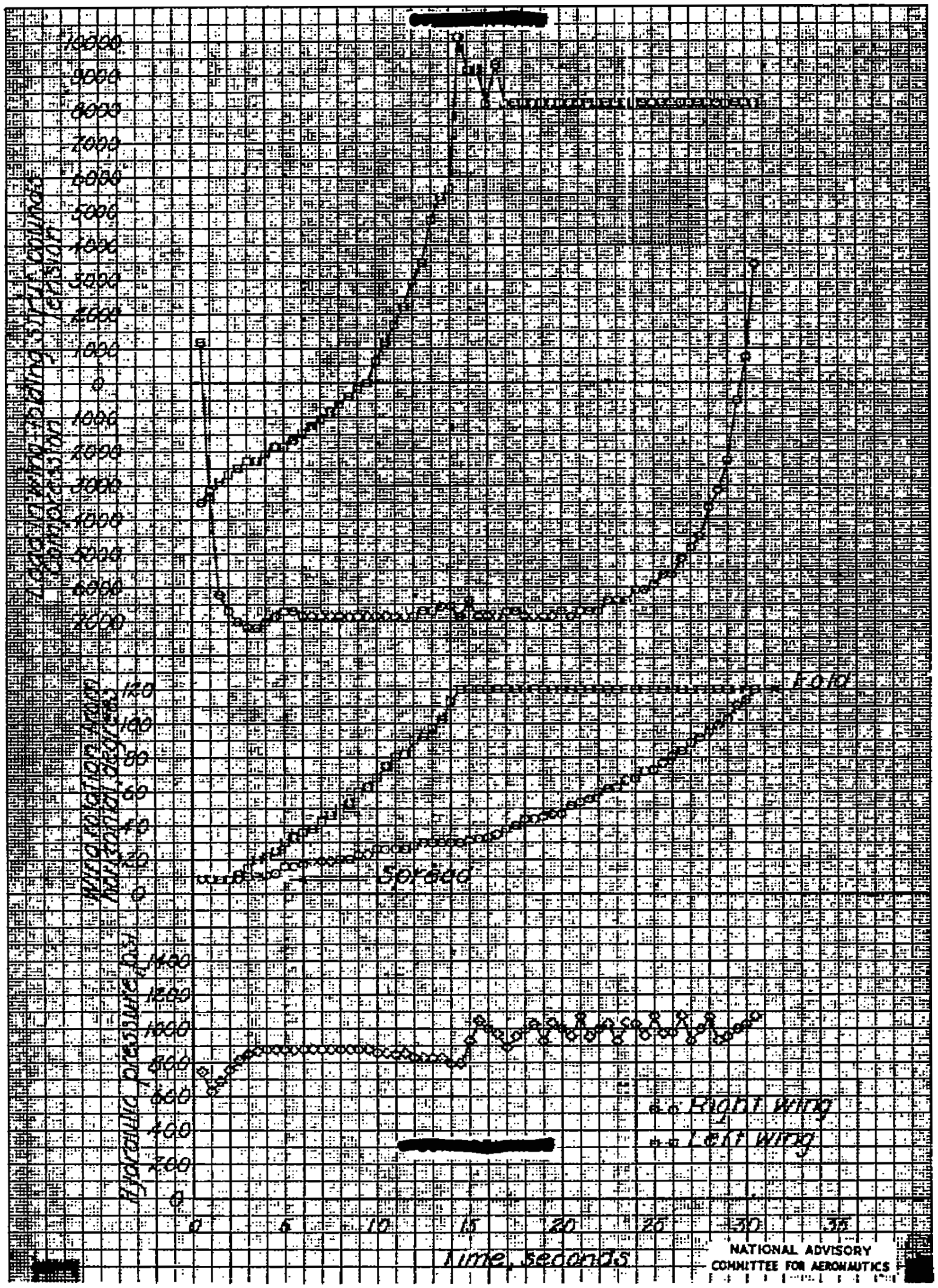

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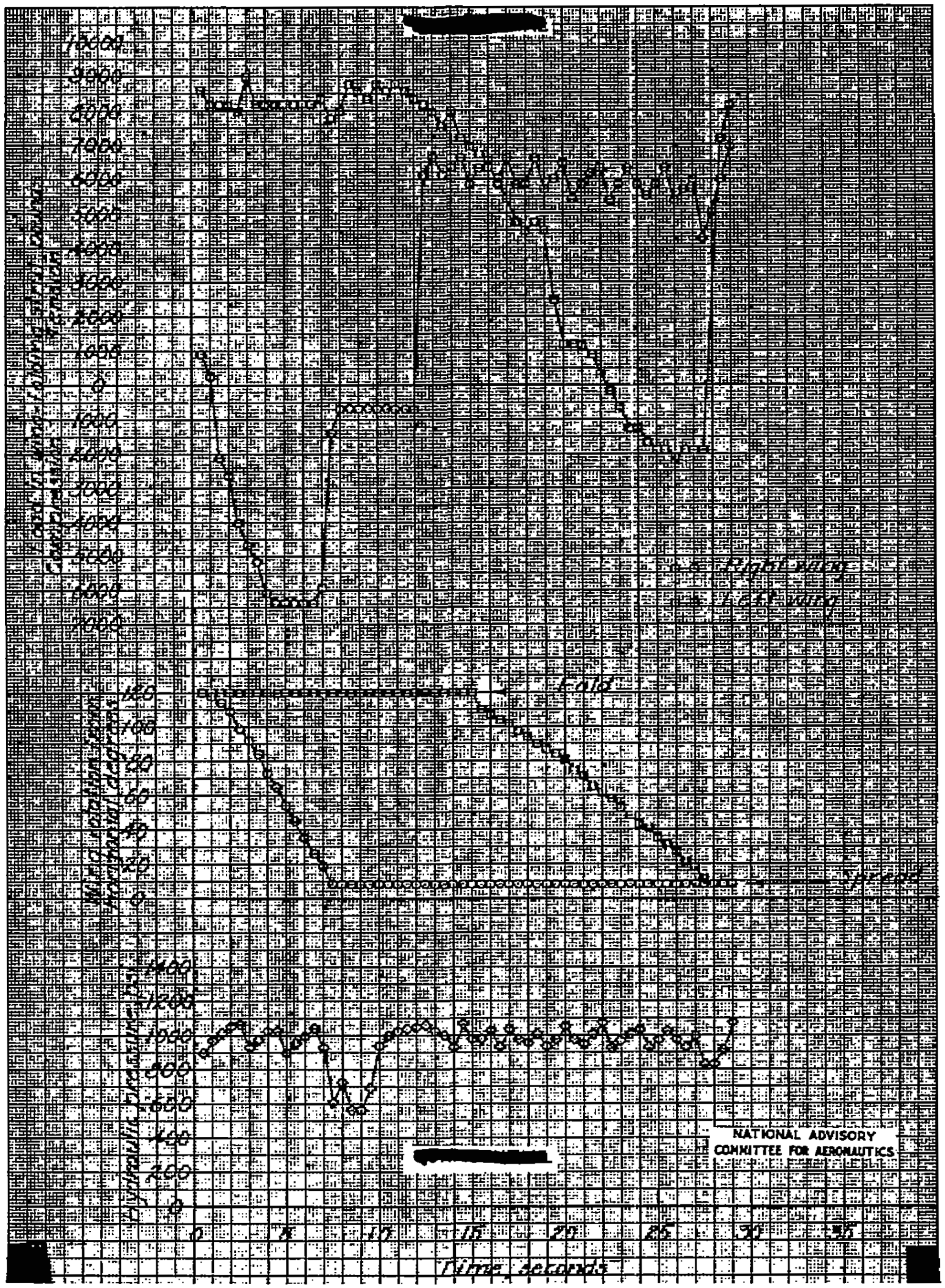
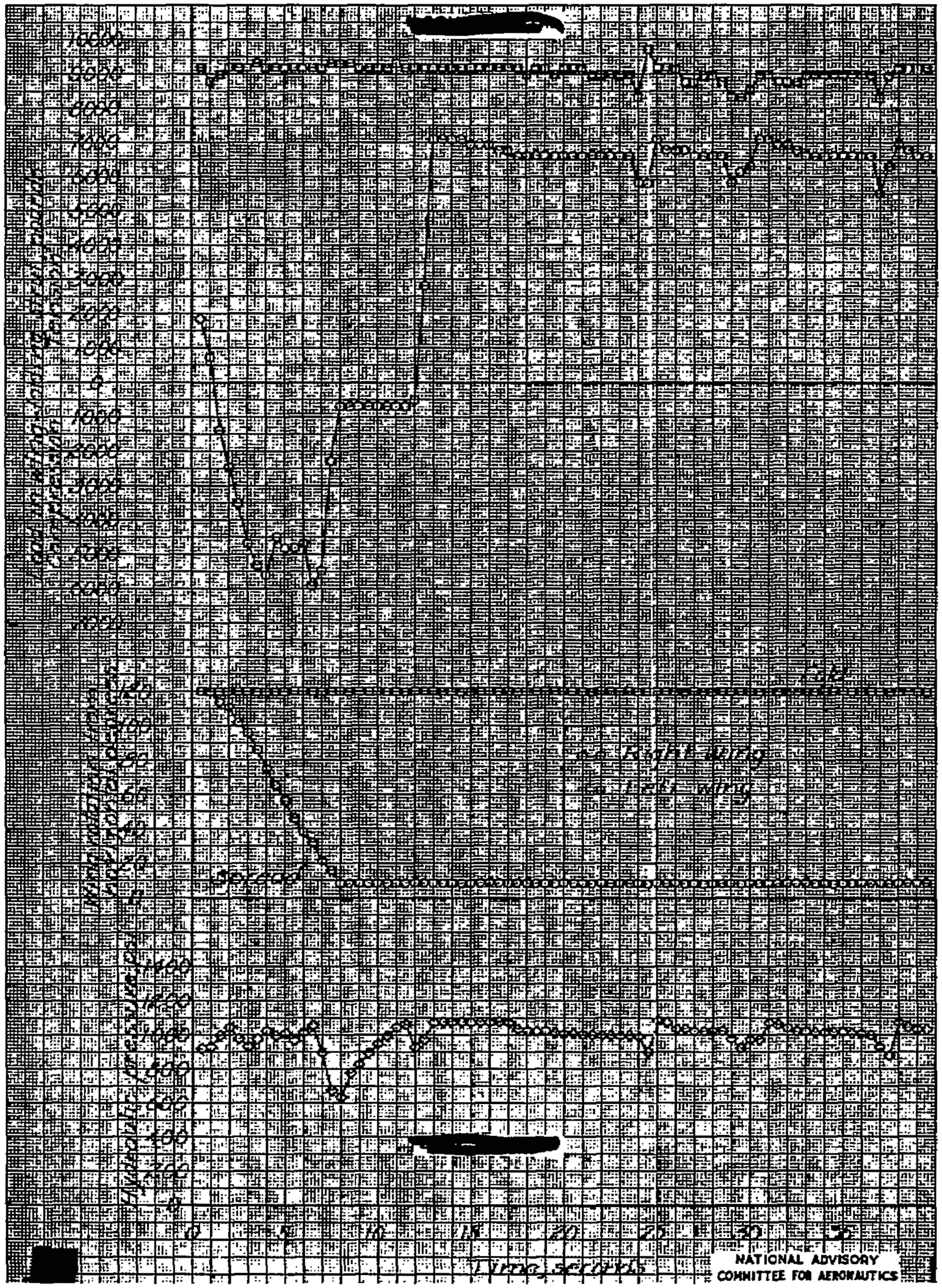
(a) Typical folding operation (Test record 1): 20° yaw, 33 knots, 1100 psi regulator setting, rockets on downstream wing only, full ammunition load, original aileron linkages.

Figure 9.- Actual values showing both the load variations in the wing-folding struts for the typical test records presented in figure 8, and also the variation of the hydraulic pressure and wing position with time for the same test conditions. F4U-1D airplane.



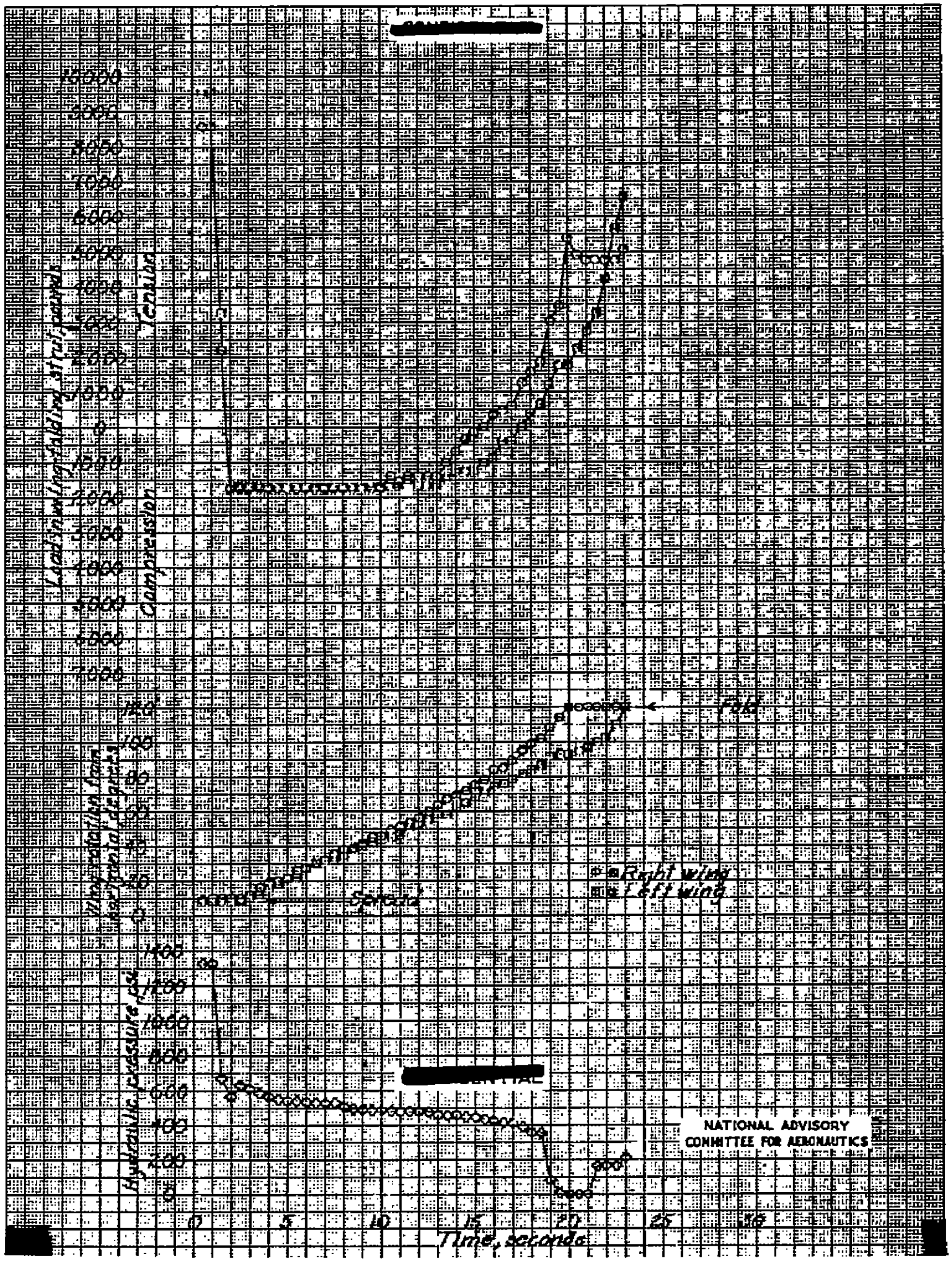
(b) Typical spreading operation (Test record 2): 20° yaw, 33 knots, 1100 psi regulator setting, rockets on downstream wing only, full ammunition load, original aileron linkages.

Figure 9.- Continued.



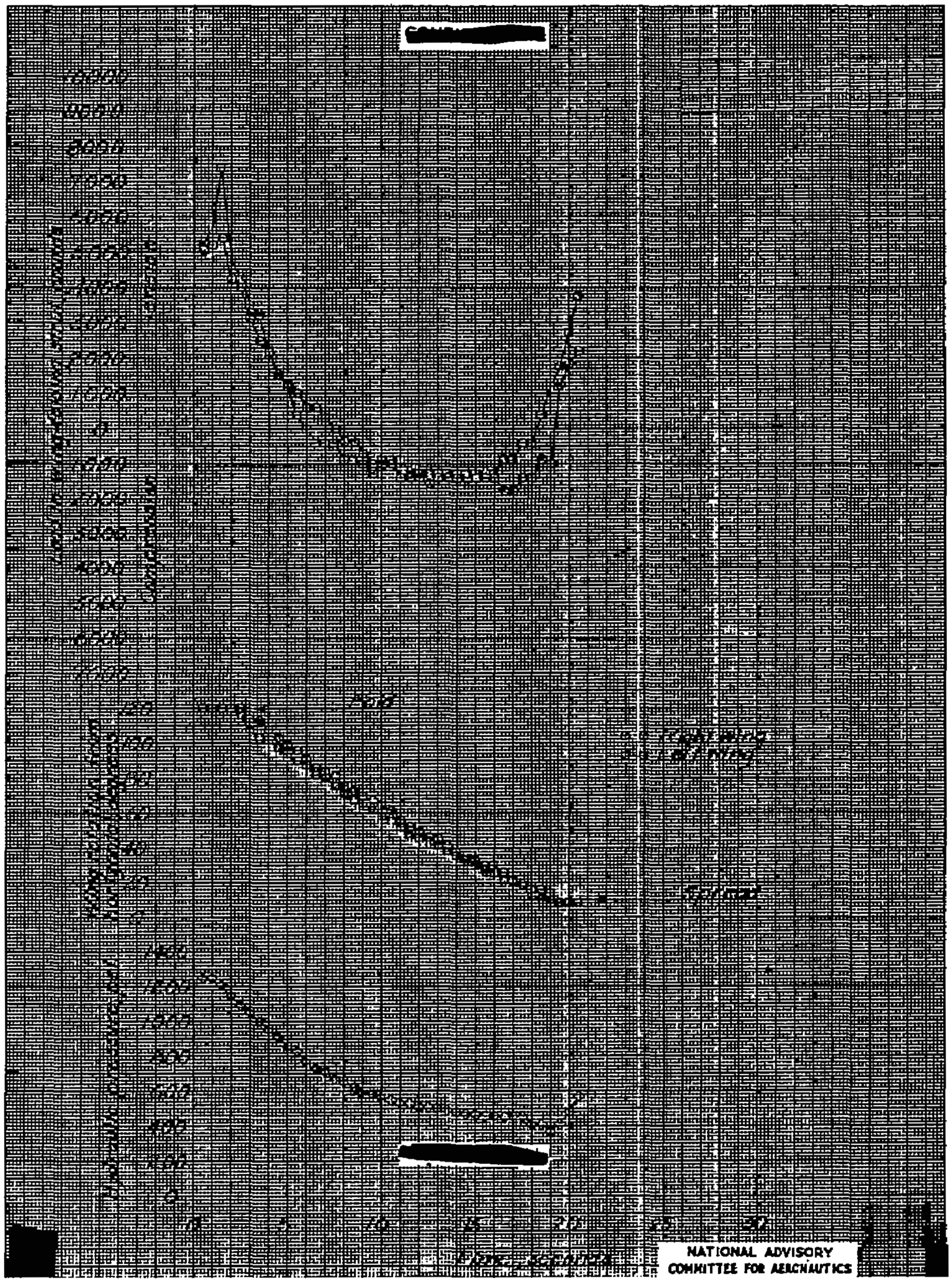
(c) Typical spreading operation (Test record 3): 20° yaw, 35.6 knots, 1100 psi regulator setting, rockets on downstream wing only, full ammunition load, original aileron linkages.

Figure 9.- Continued.



(d) Typical folding operation (Test record 4):
0° yaw, 45 knots, 1450 psi regulator setting,
rockets removed, full ammun'tion load,
modified aileron linkages.

Figure 9.- Continued.



(e) Typical spreading operation (Test record 5): 0° yaw, 45 knots, 1450 psi regulator setting, rockets removed, full ammunition load, modified aileron linkages.

Figure 9.- Concluded.

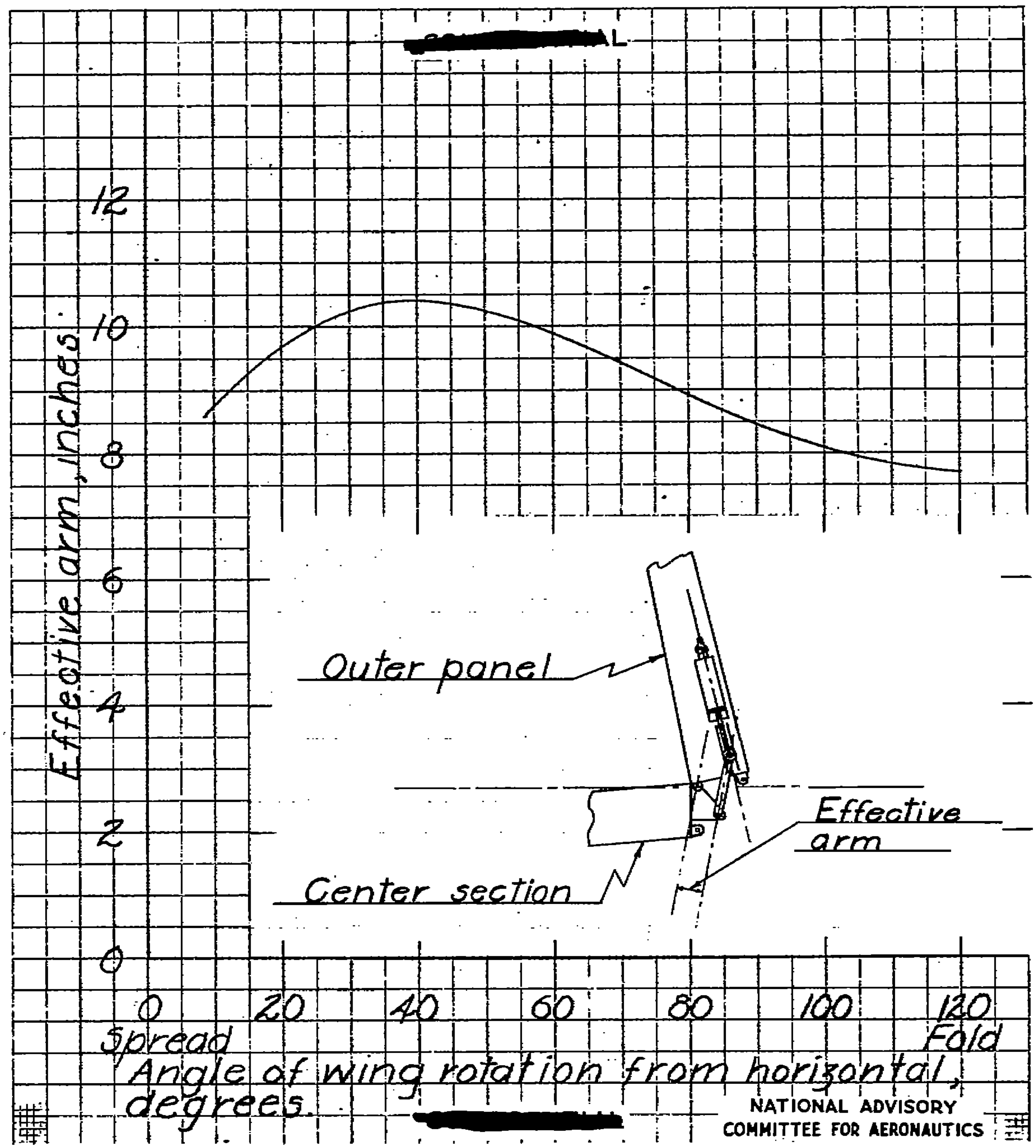


Figure 10.- Variation of effective arm with wing position. F4U-1D airplane.

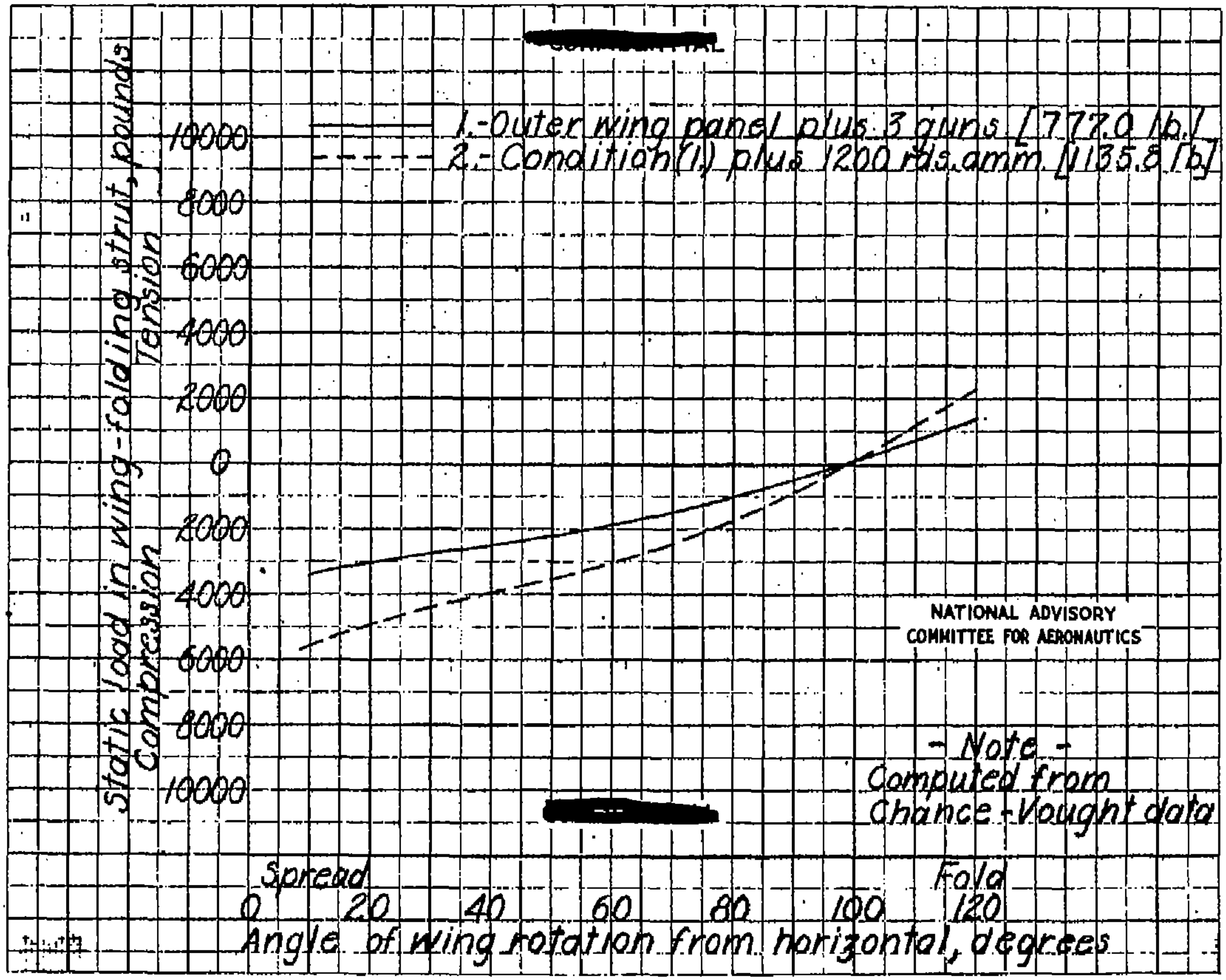


Figure 11.- Variation of approximate static load in wing-folding strut with wing position. F4U-1D airplane.

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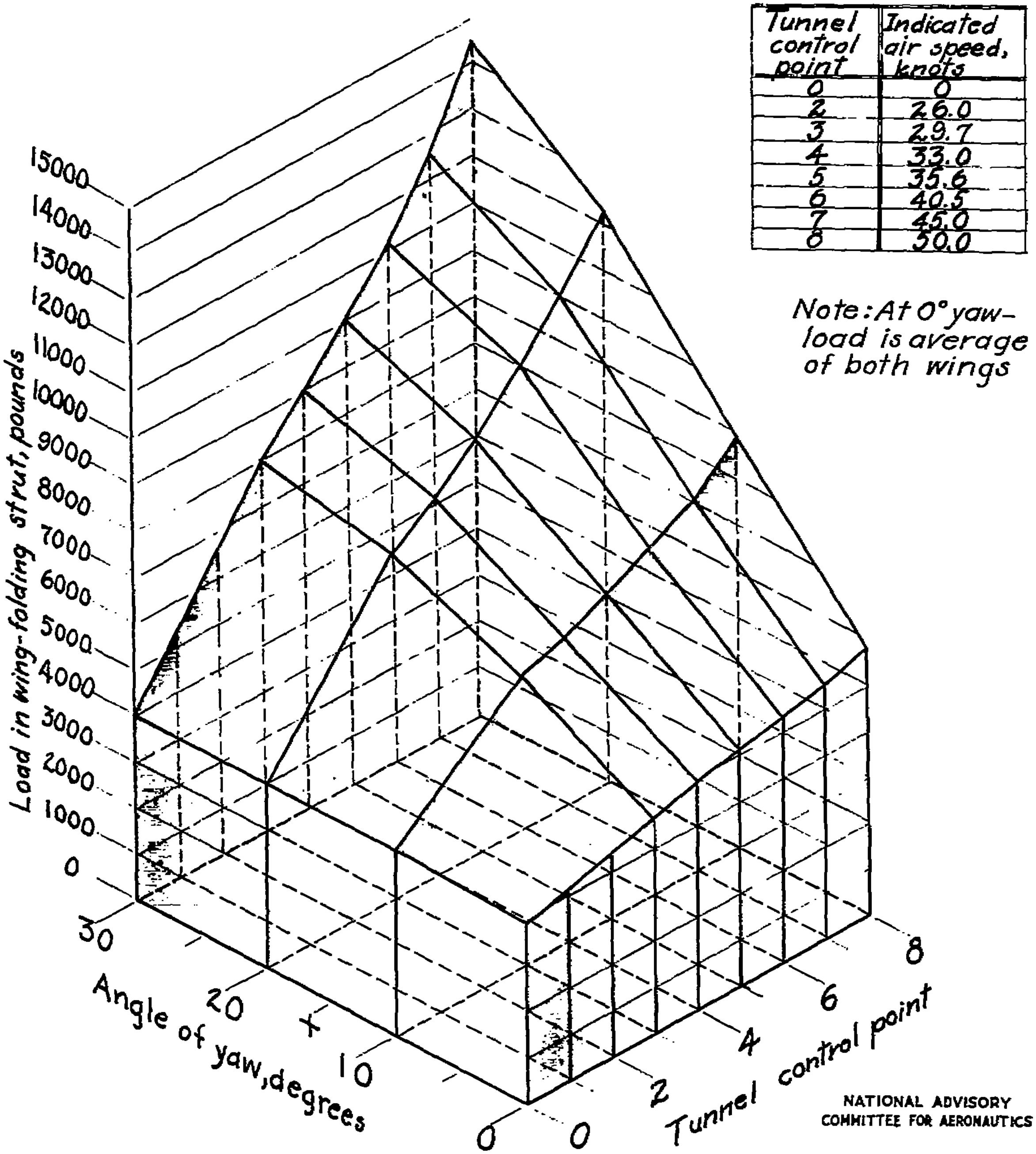

Tunnel control point	Indicated air speed, knots
0	0
2	26.0
3	29.7
4	33.0
5	35.6
6	40.5
7	45.0
8	50.0

Figure 12.- Variation with angle of yaw and airspeed of the average load in the folding strut of the upstream wing at the start of the spreading operation. F4U-1D airplane.

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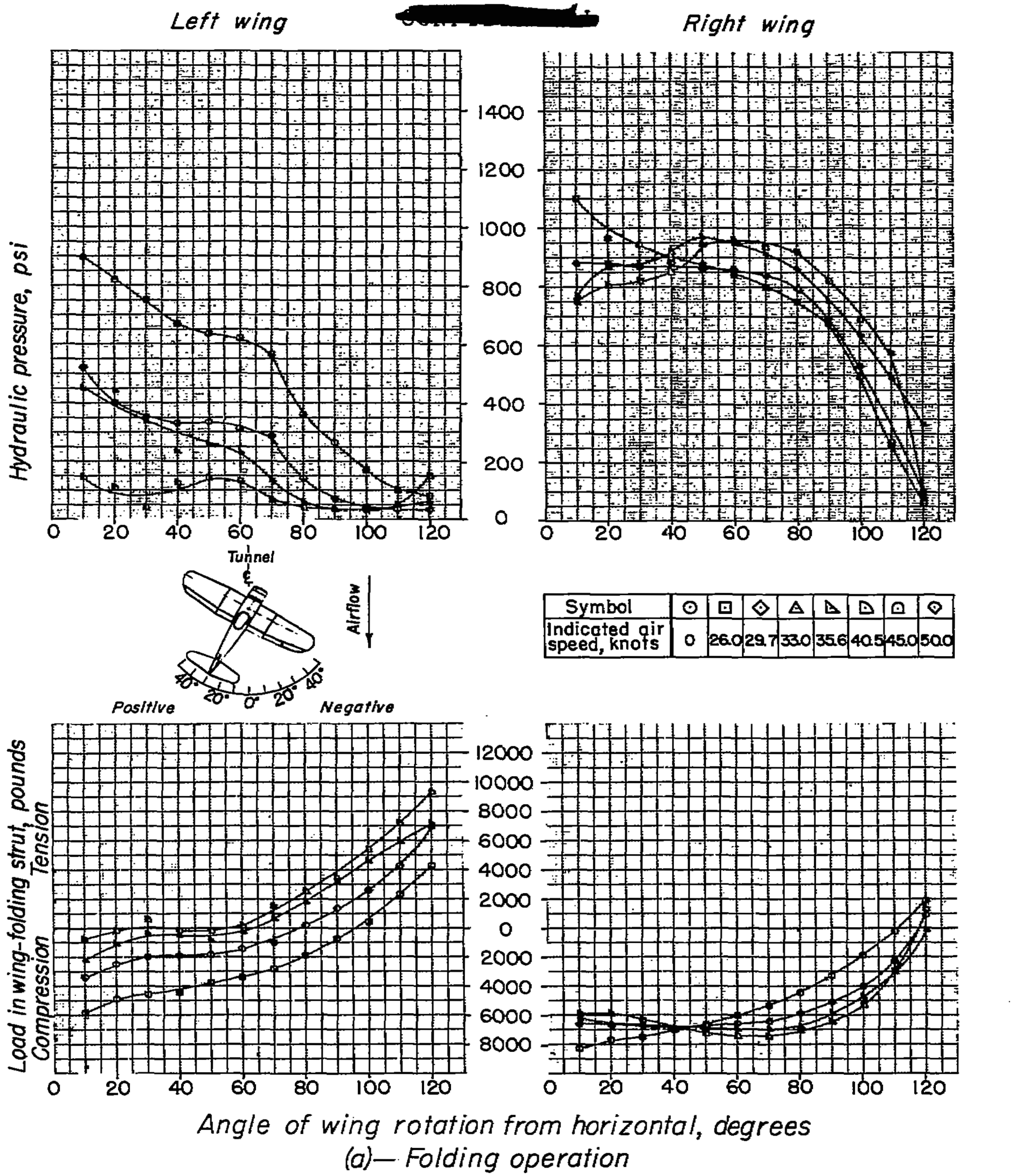

Figure 13.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 30° yaw; 1450 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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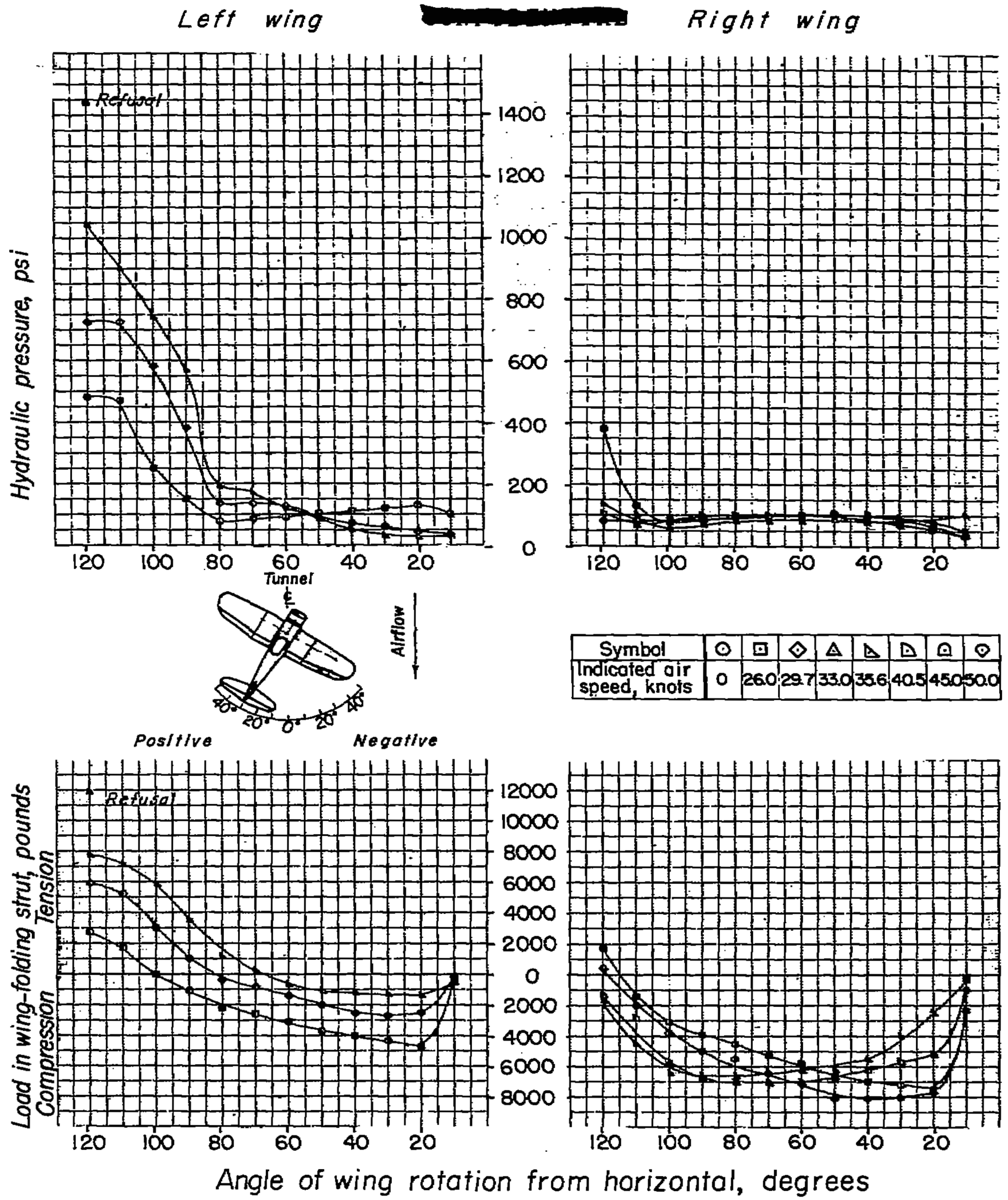

Symbol	⊙	⊡	◇	△	◺	◹	⌂	♢
Indicated air speed, knots	0	26.0	29.7	33.0	35.6	40.5	45.0	50.0

(b)— Spreading operation

Figure 13.- Concluded

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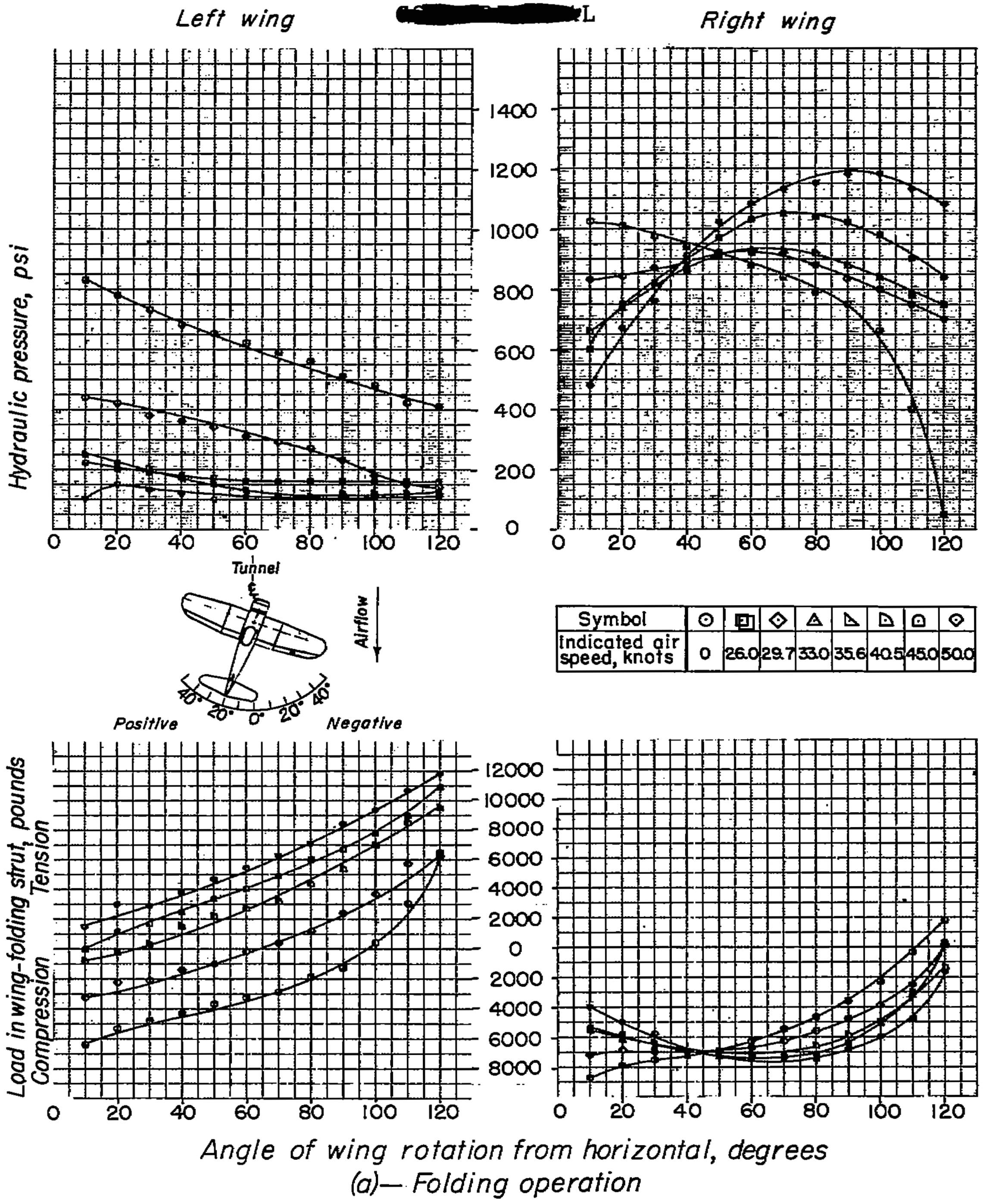

Figure 14.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 20° yaw; 1450 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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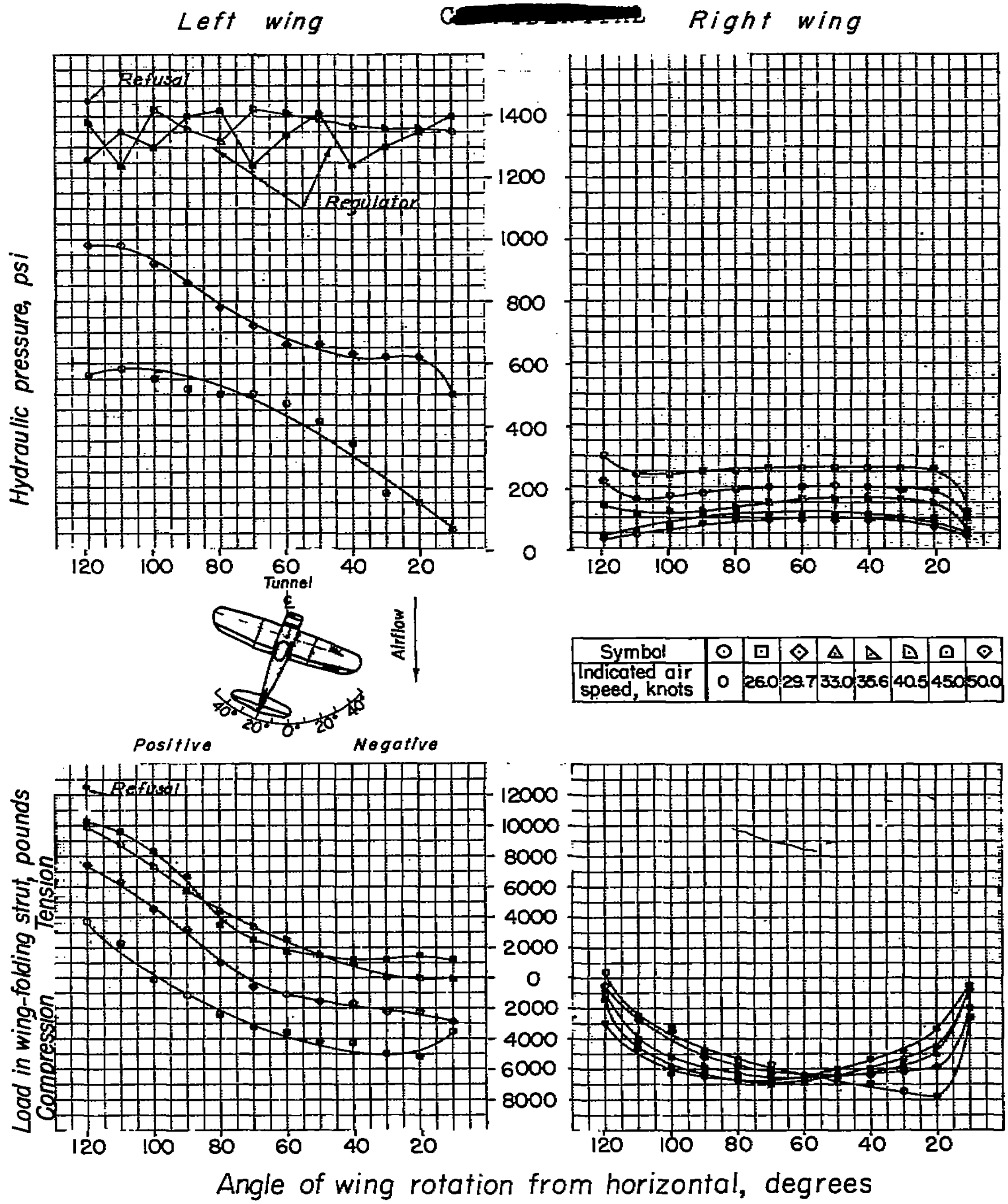

(b)— Spreading operation

Figure 14.- Concluded

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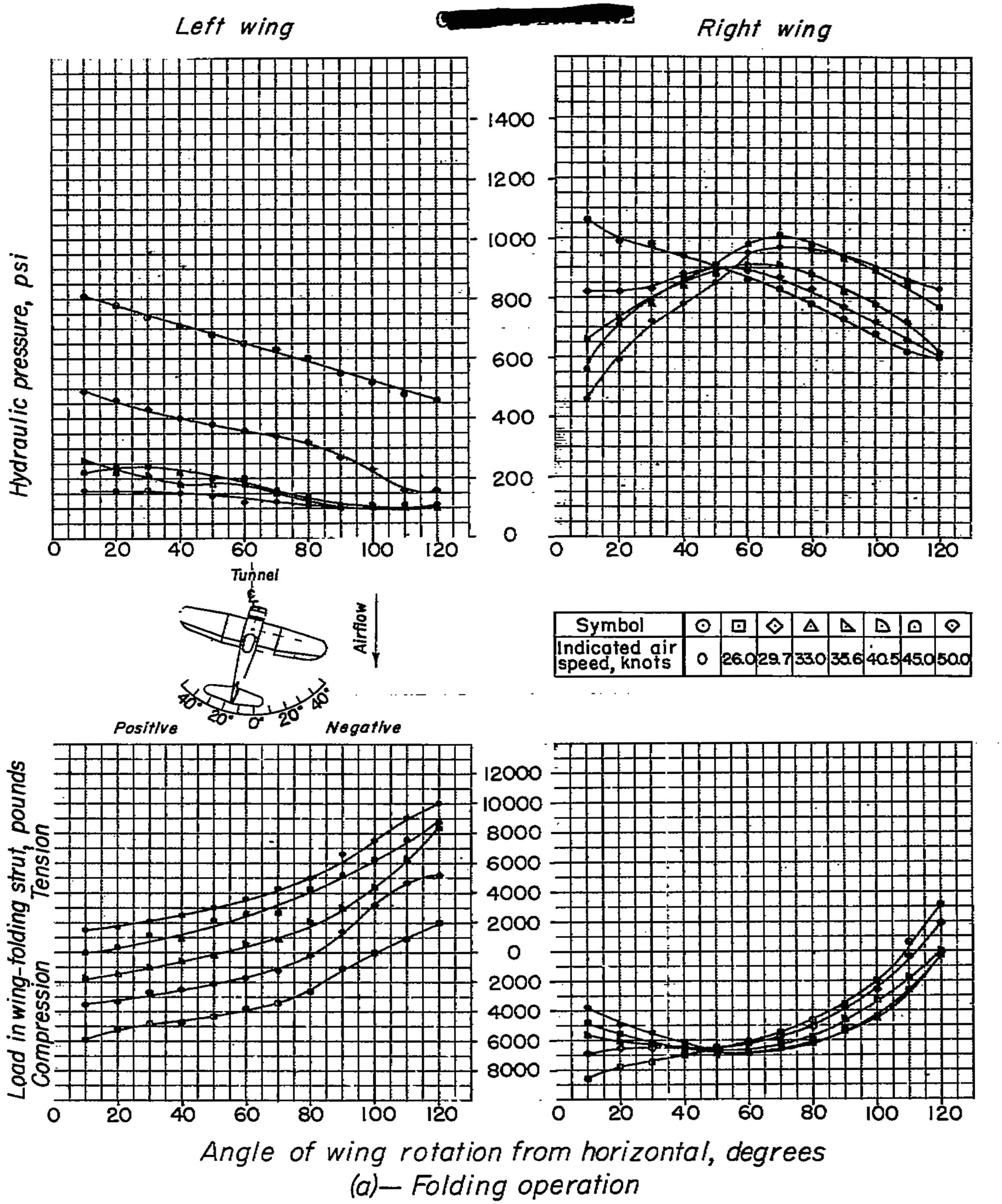

Symbol	⊙	⊡	◇	△	◺	◺	⌂	◇
Indicated air speed, knots	0	26.0	29.7	33.0	35.6	40.5	45.0	50.0

Figure 15.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 15° yaw; 1450 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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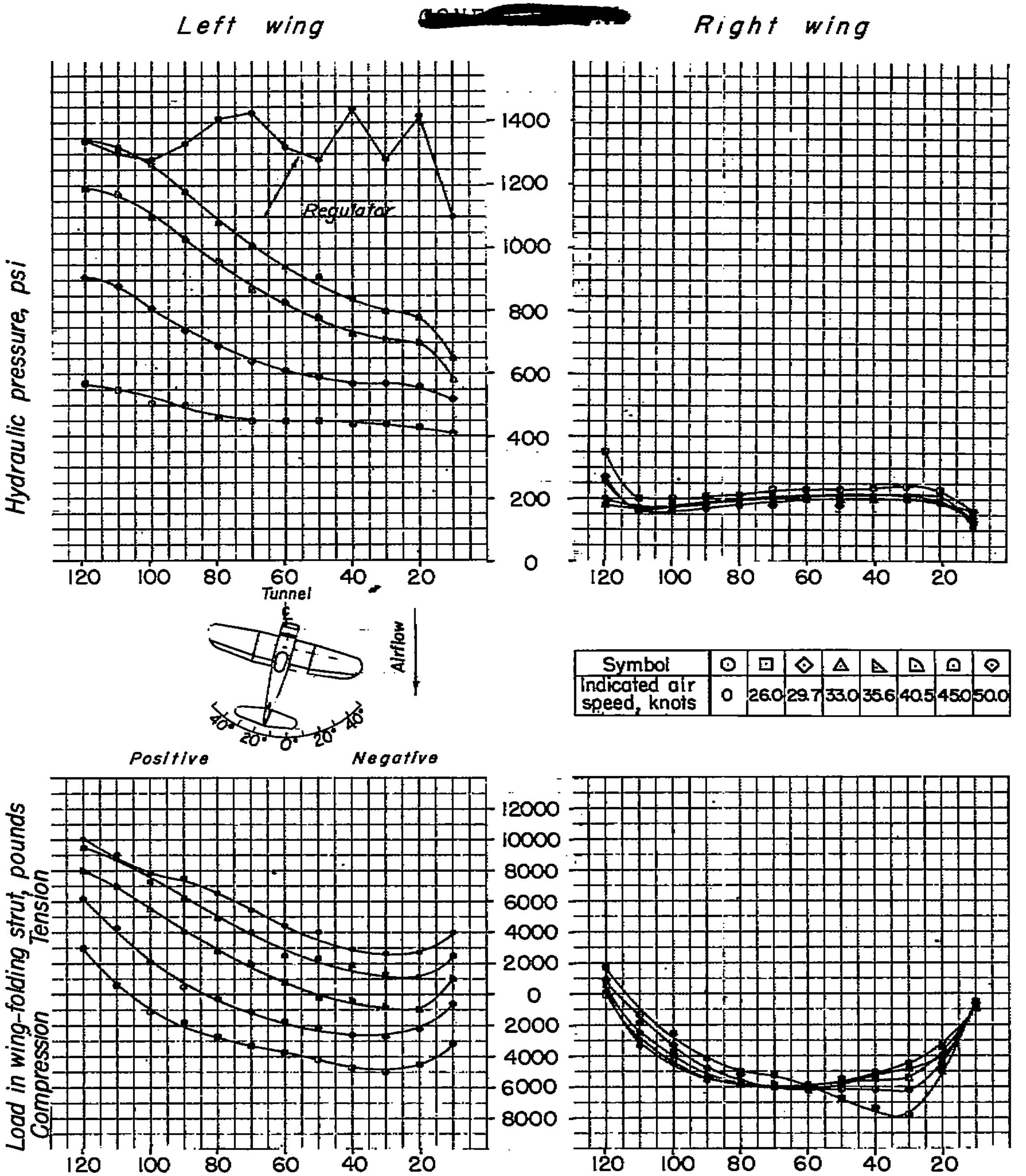

Symbol	⊙	⊡	◇	△	◺	◺	⌂	◇
Indicated air speed, knots	0	26.0	29.7	33.0	35.6	40.5	45.0	50.0

(b)— Spreading operation

Figure 15.- Concluded

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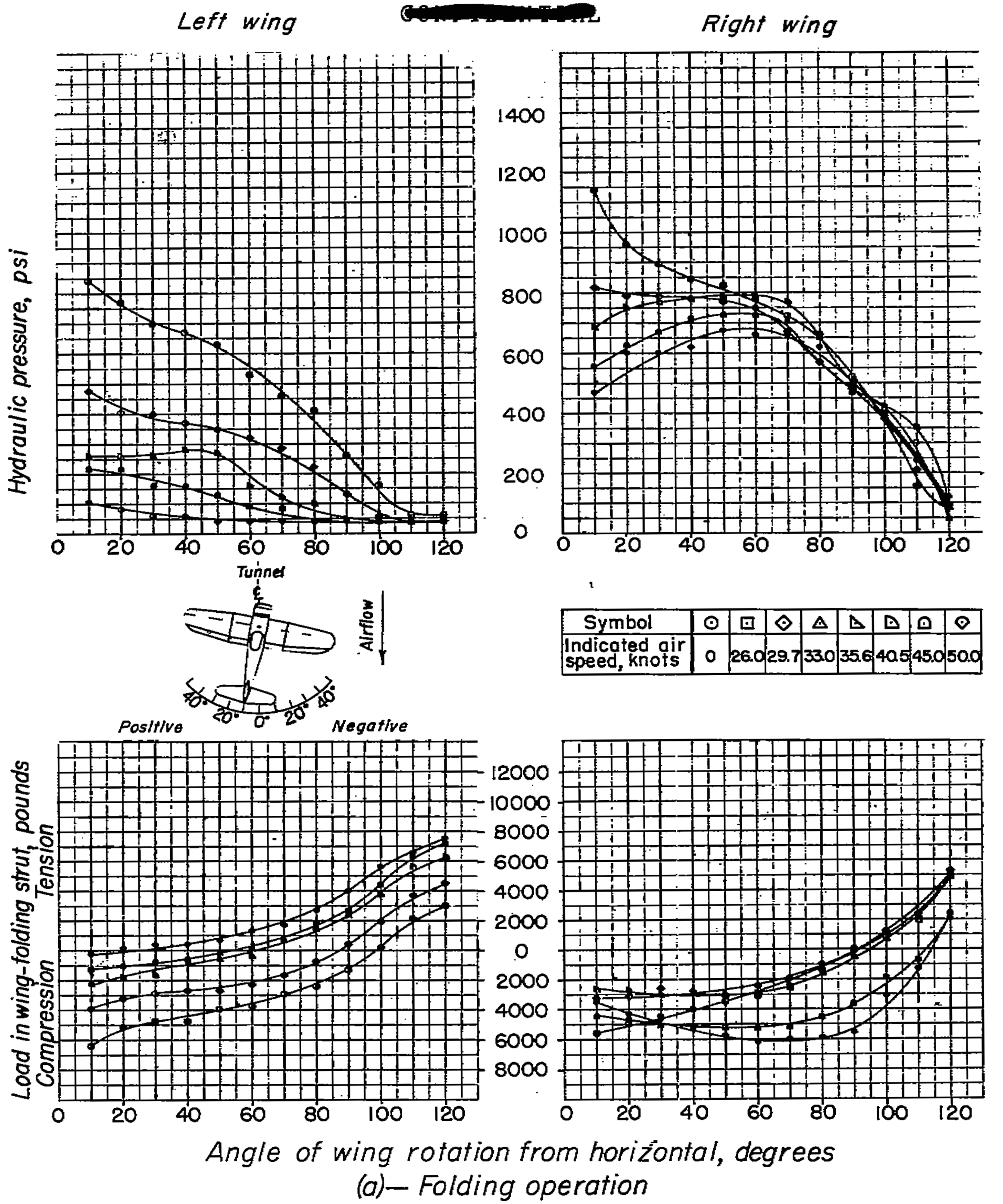

Figure 16.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 10° yaw; 1350 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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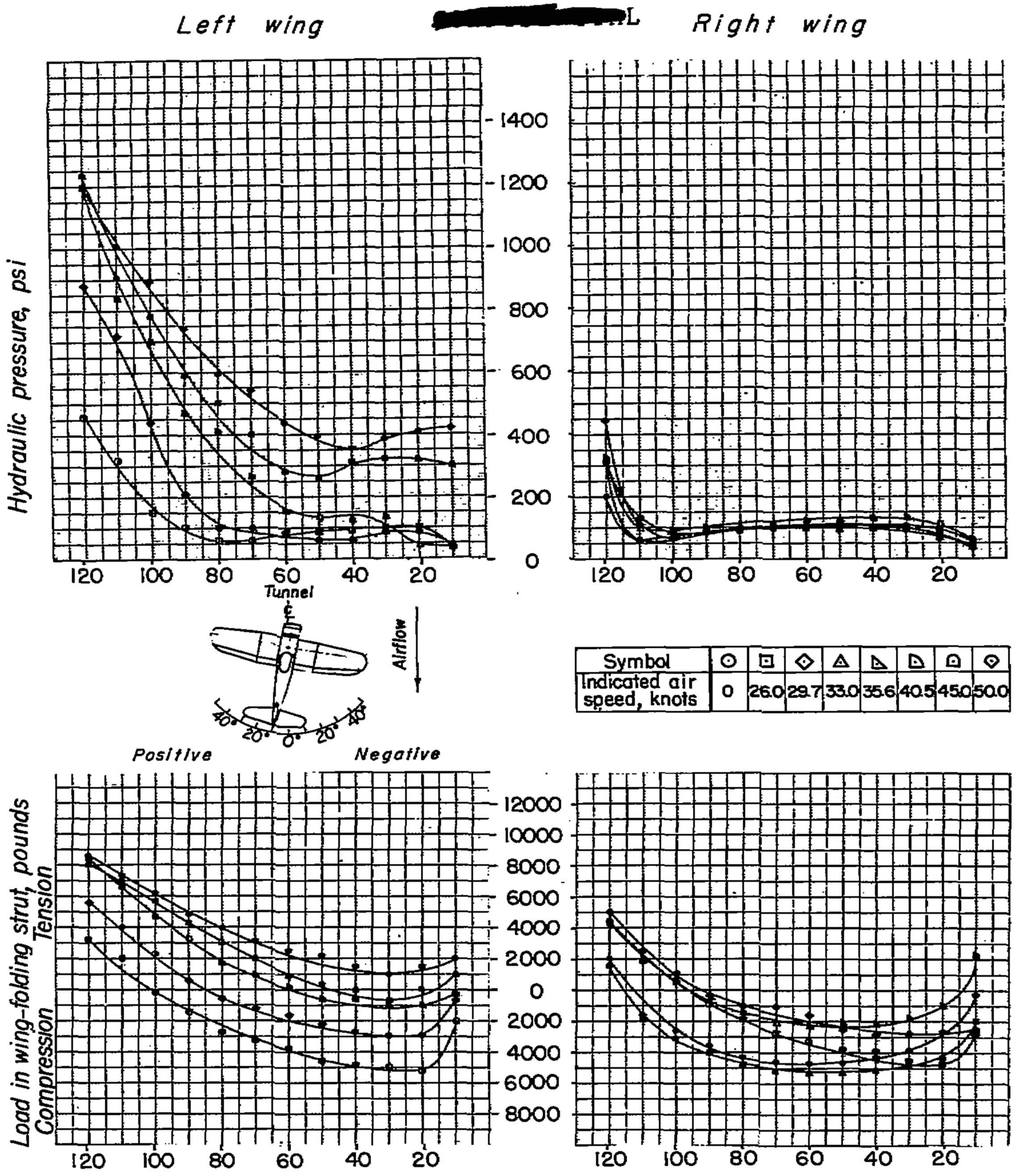

(b)— Spreading operation

Figure 16.- Concluded

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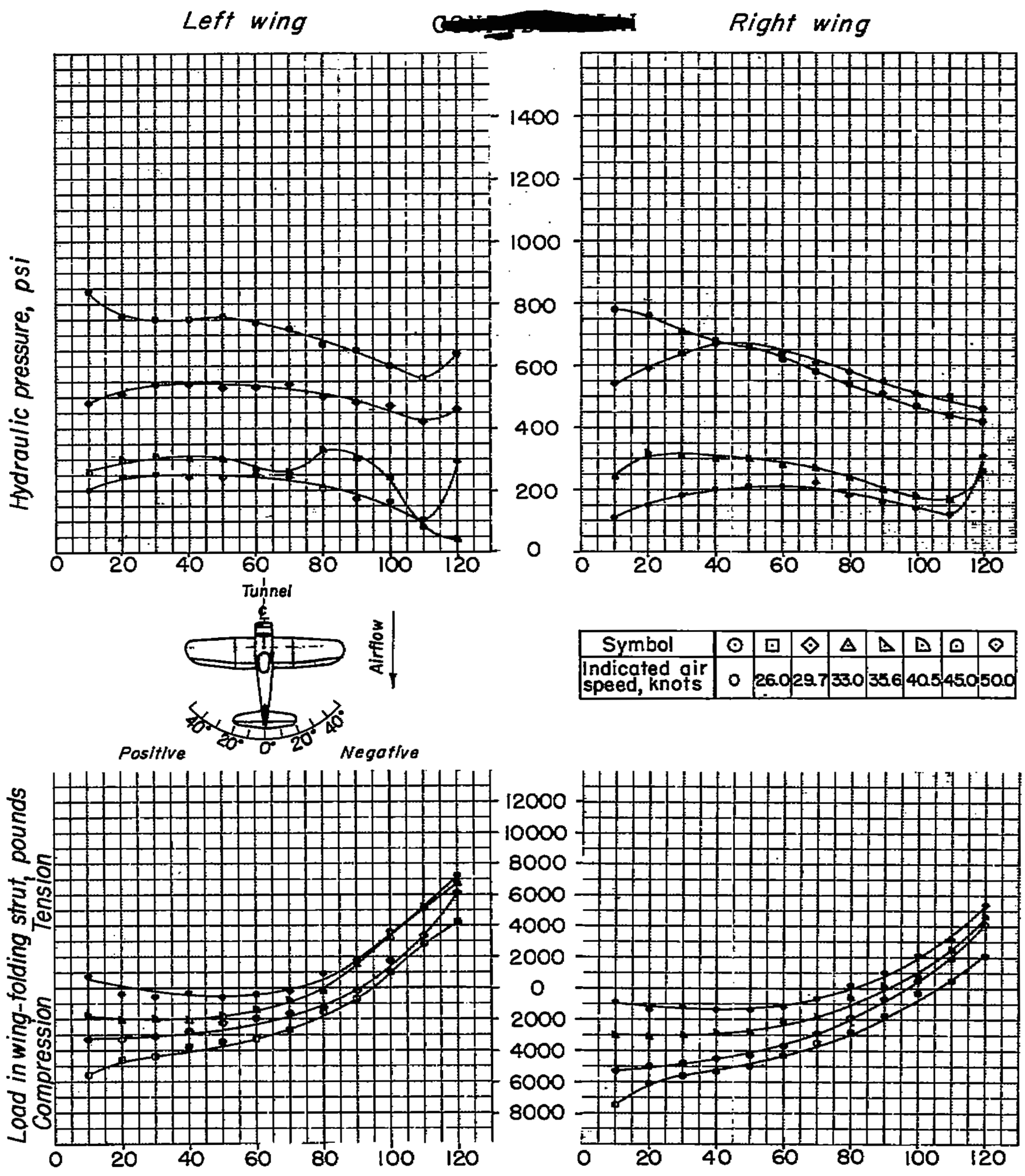

Symbol	⊙	⊡	◇	△	◺	◹	◠	♢
Indicated air speed, knots	0	26.0	29.7	33.0	35.6	40.5	45.0	50.0

Figure 17.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for 0° yaw; 1450 psi regulator setting, modified aileron linkages, rockets removed, full ammunition load. F4U-1D airplane.

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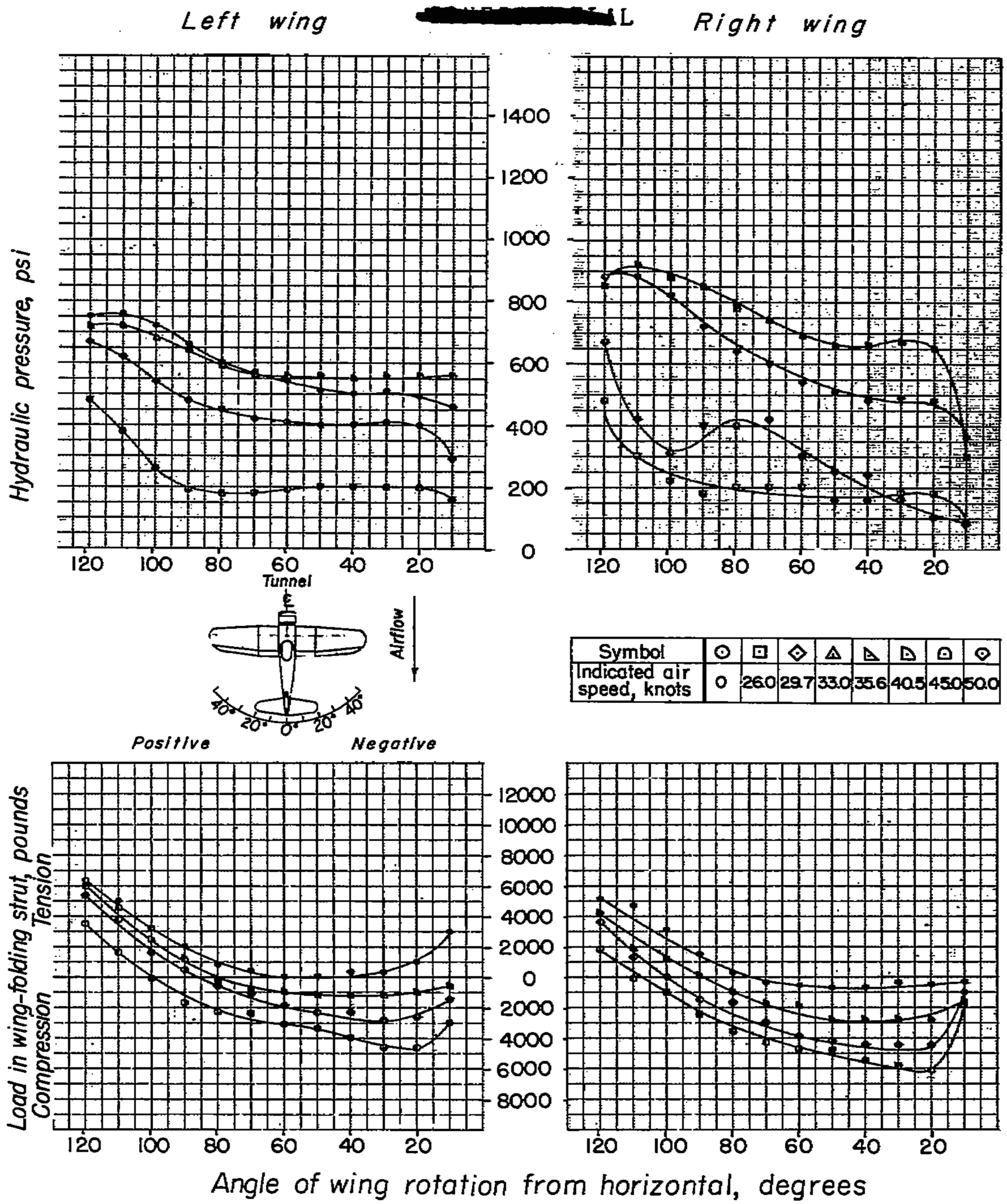

(b)— Spreading operation

Figure 17.- Concluded

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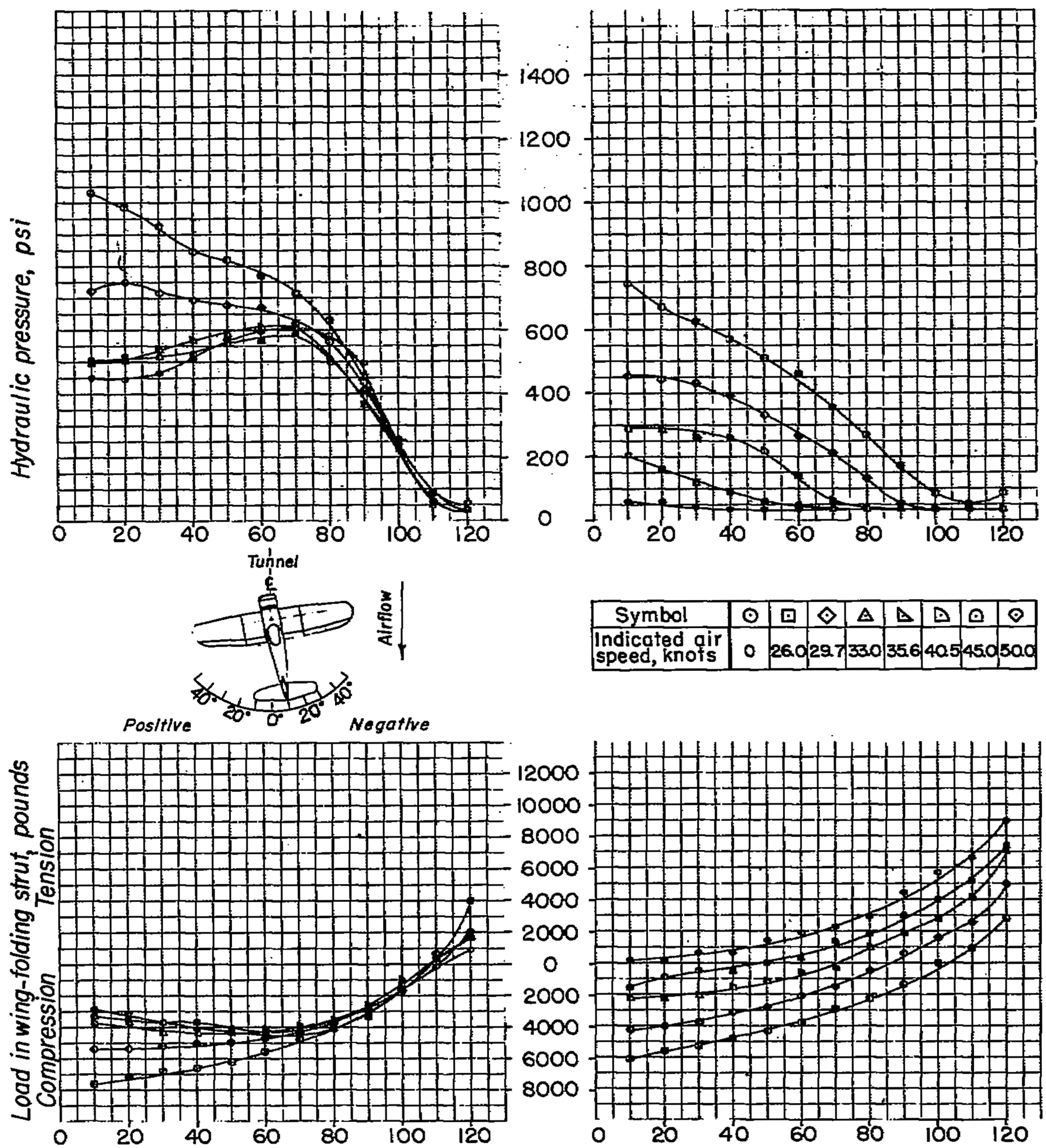

Symbol	⊙	⊡	◇	△	◺	◿	◠	◇
Indicated air speed, knots	0	26.0	29.7	33.0	35.6	40.5	45.0	50.0

(a)— Folding operation

Figure 18.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -10° yaw; 1350 psi regulator setting, modified aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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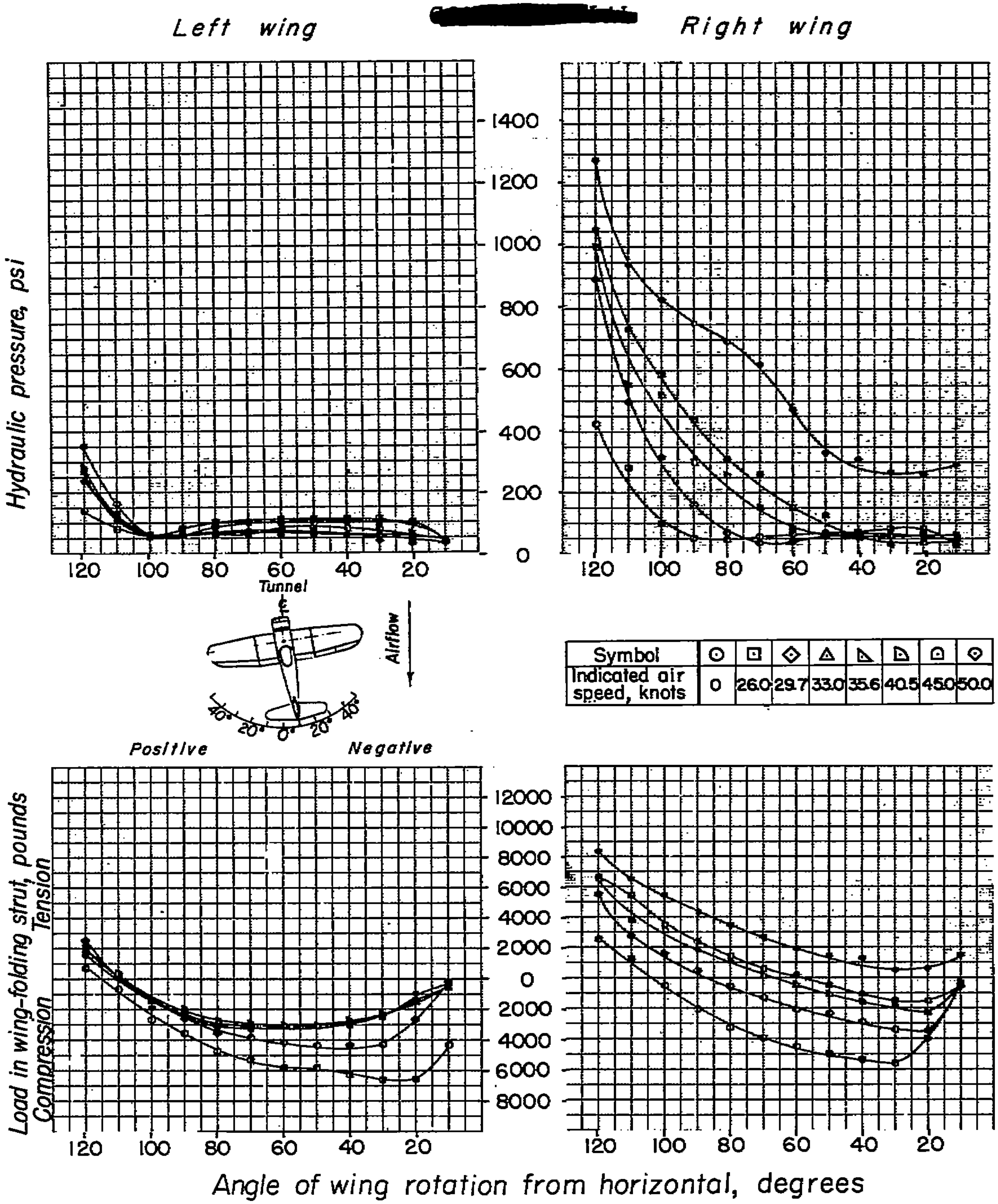

(b)— Spreading operation

Figure 18.- Concluded

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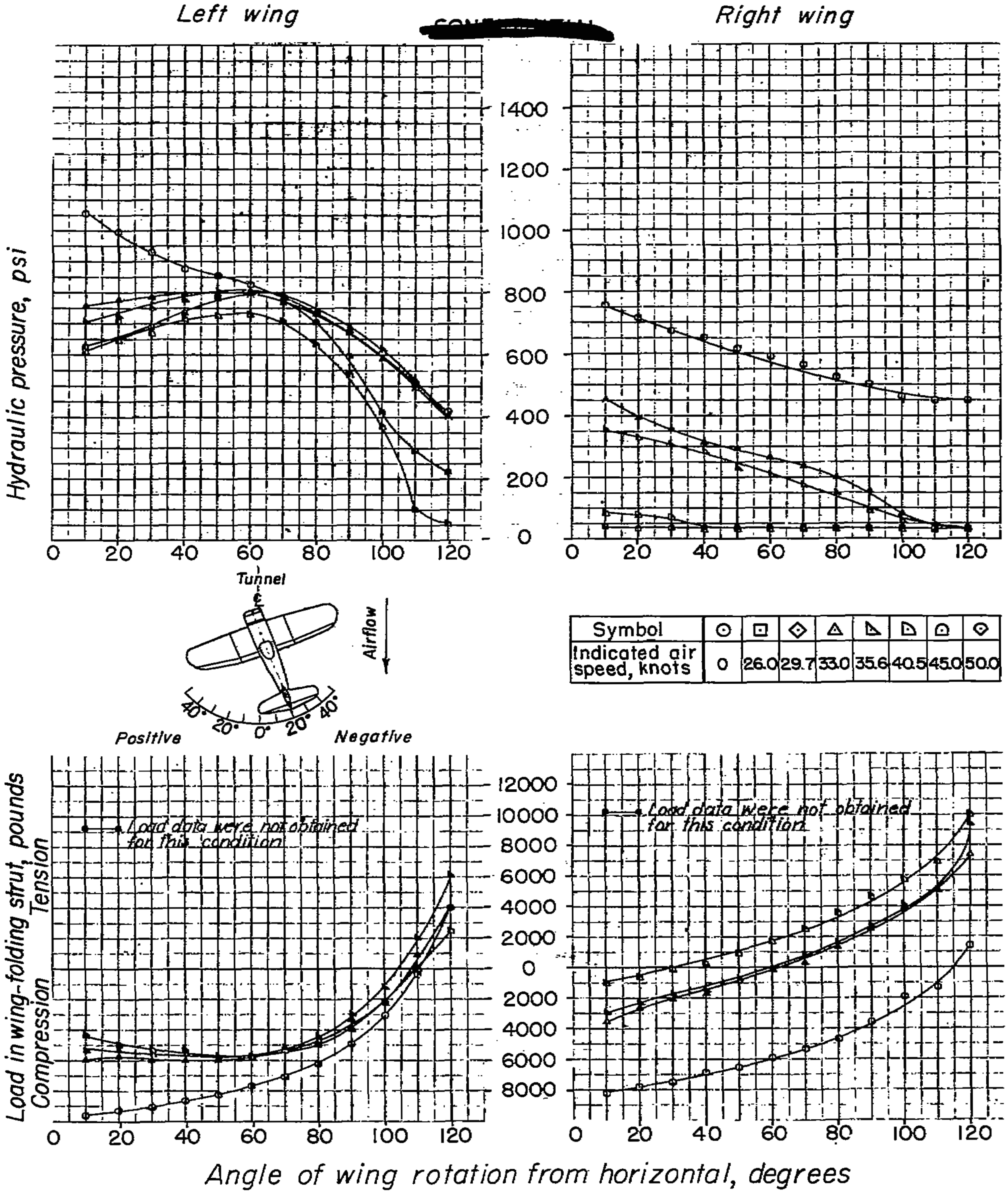

(a)— Folding operation

Figure 19.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -20° yaw; 1350 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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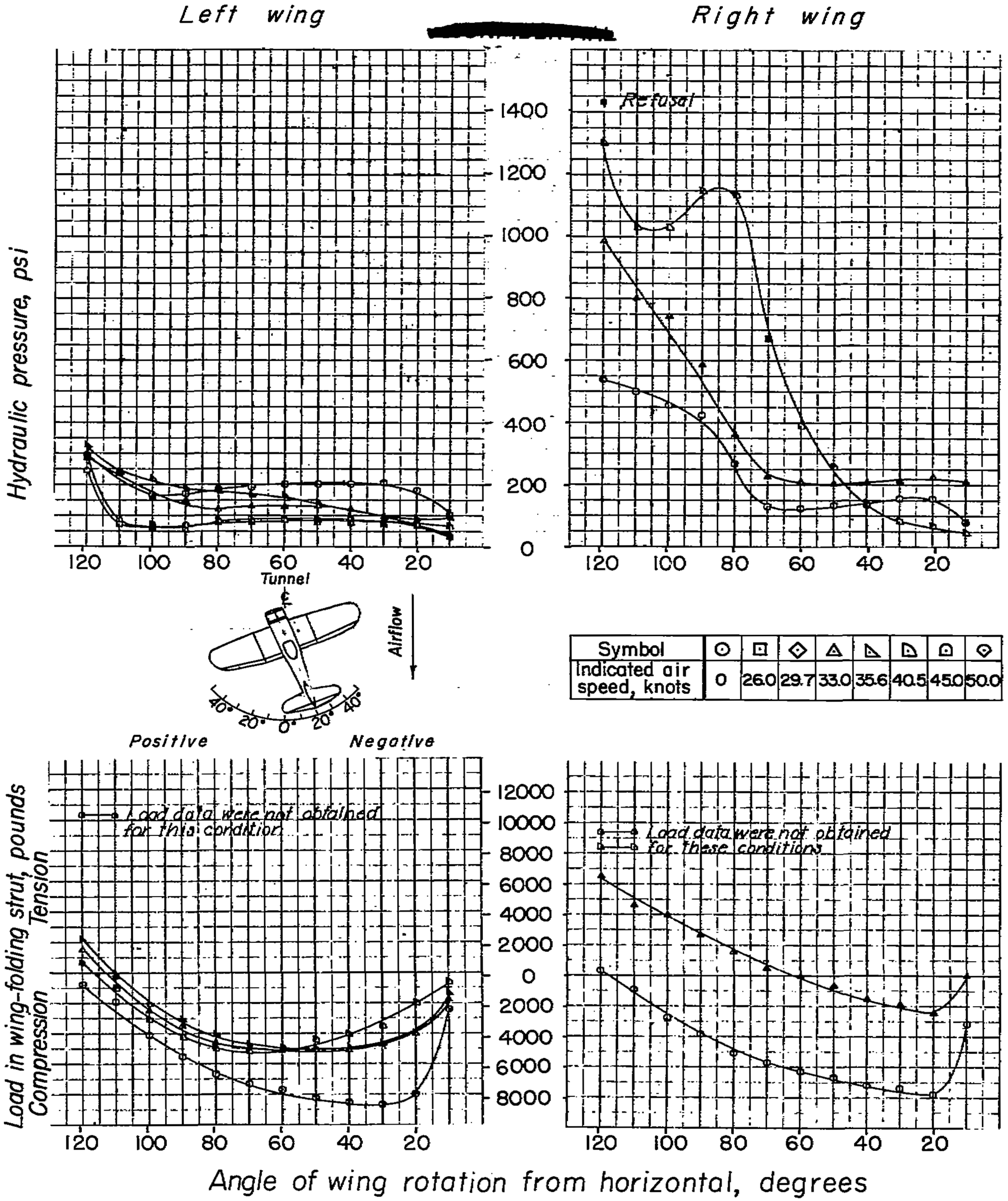

Symbol	⊙	⊡	◇	△	◺	D	⌂	◇
Indicated air speed, knots	0	26.0	29.7	33.0	35.6	40.5	45.0	50.0

(b)— Spreading operation

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Figure 19.- Concluded

[redacted]

[redacted]

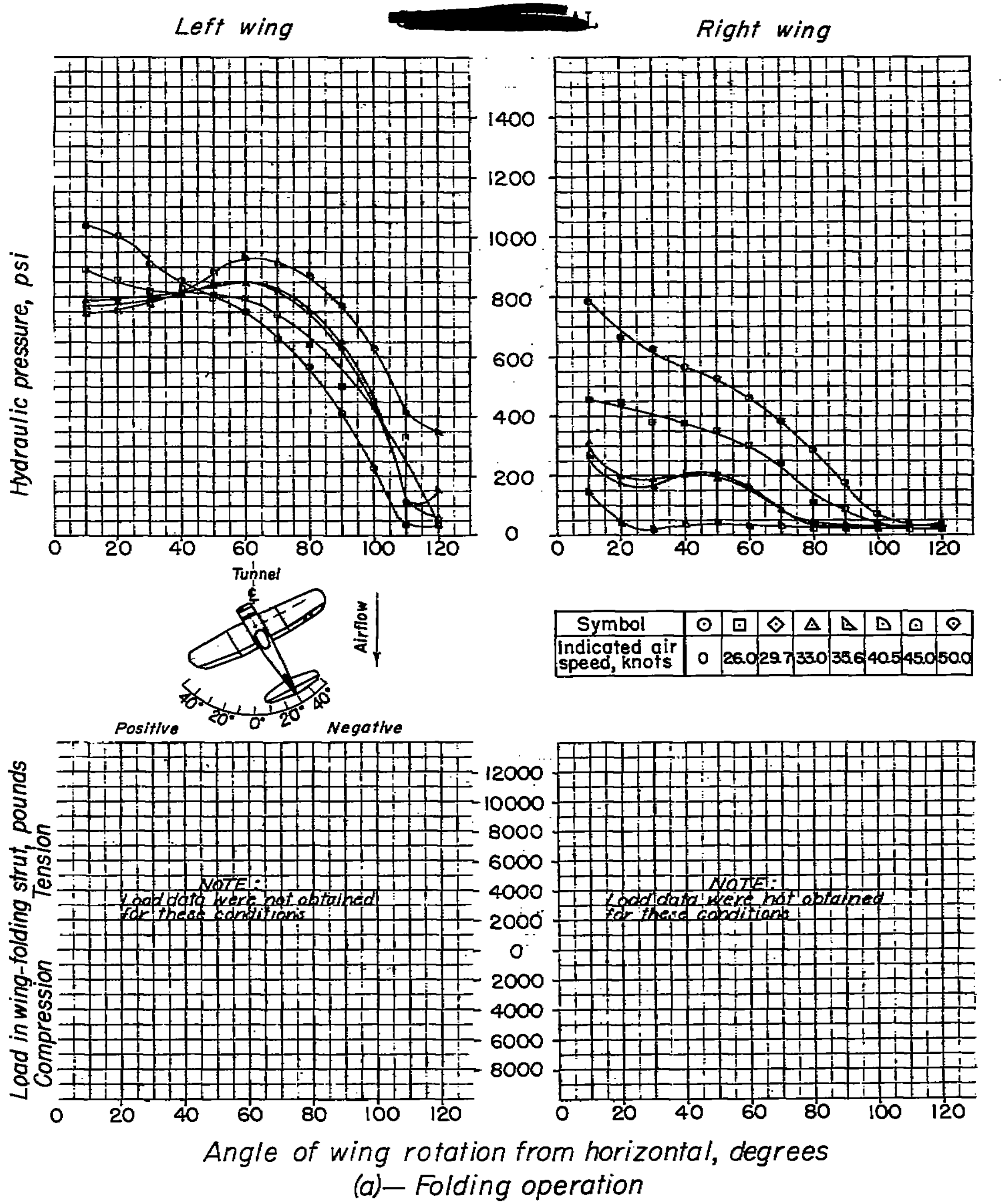

Figure 20.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -30° yaw; 1350 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U-1D airplane.

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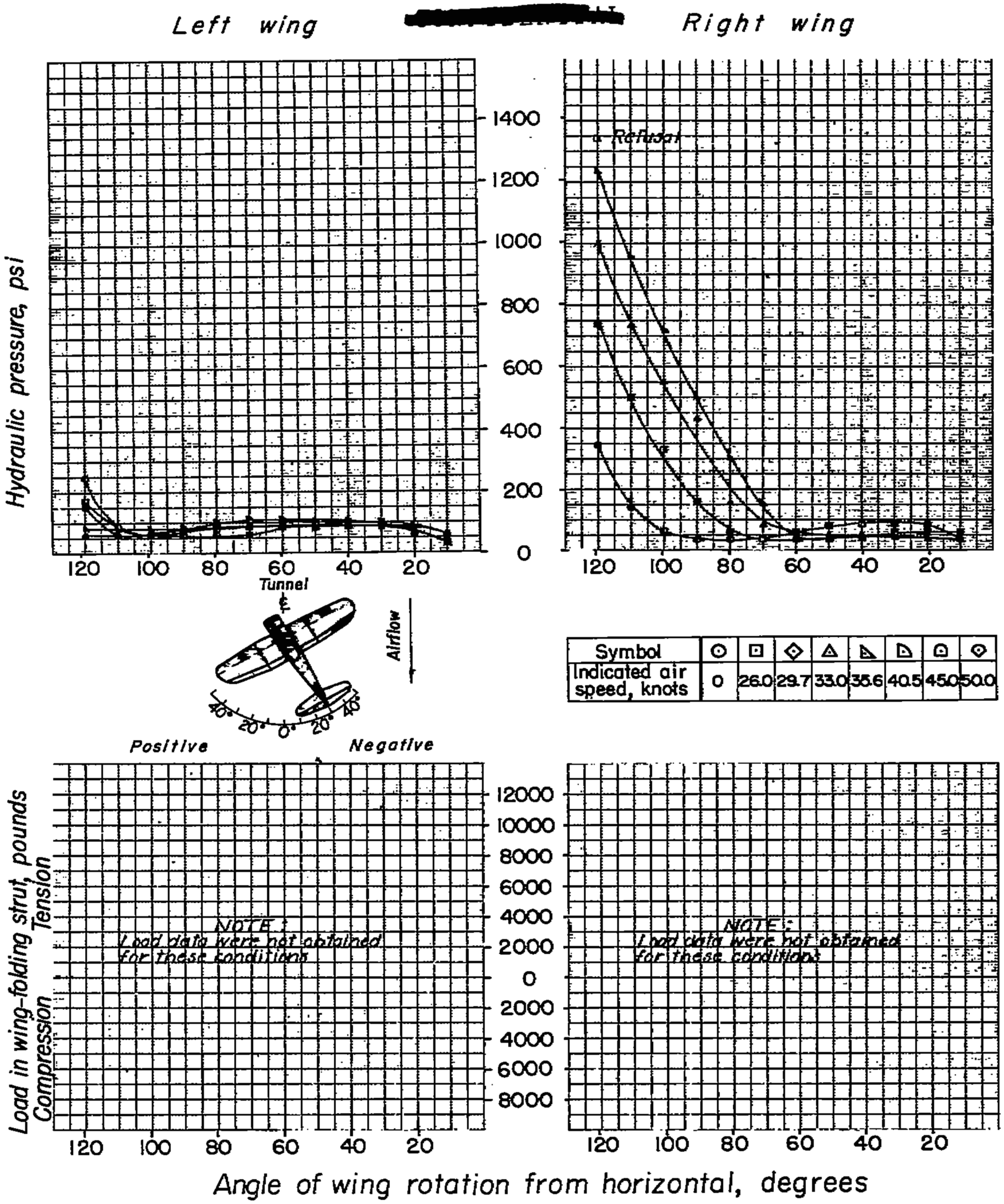

(b)— Spreading operation

Figure 20.- Concluded

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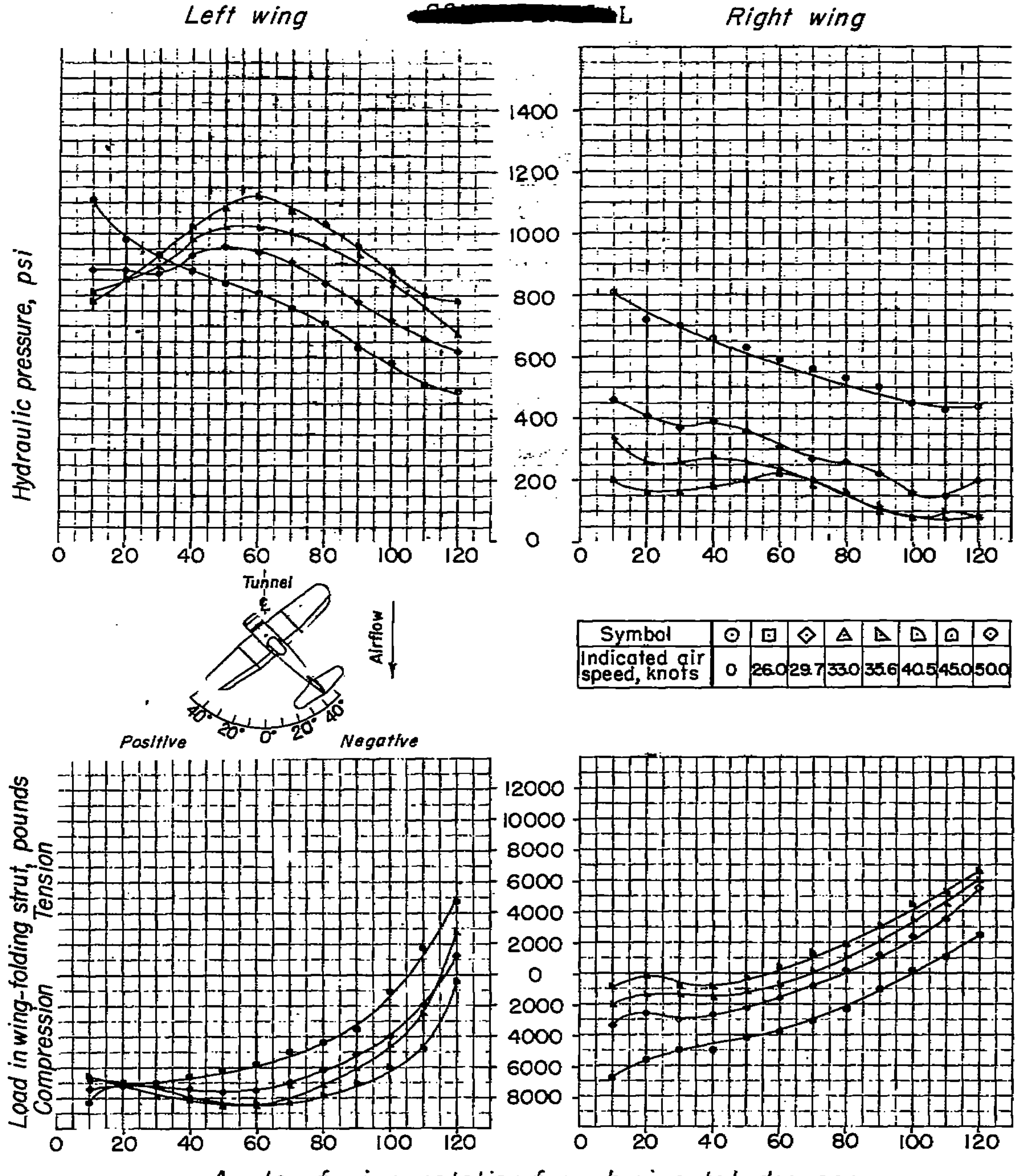

(a)— Folding operation

Figure 21.- Variation of hydraulic pressure and load in the wing-folding struts with wing position for -45° yaw; 1350 psi regulator setting, original aileron linkages, rockets on downstream wing only, full ammunition load. F4U- 1D airplane.

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[redacted]

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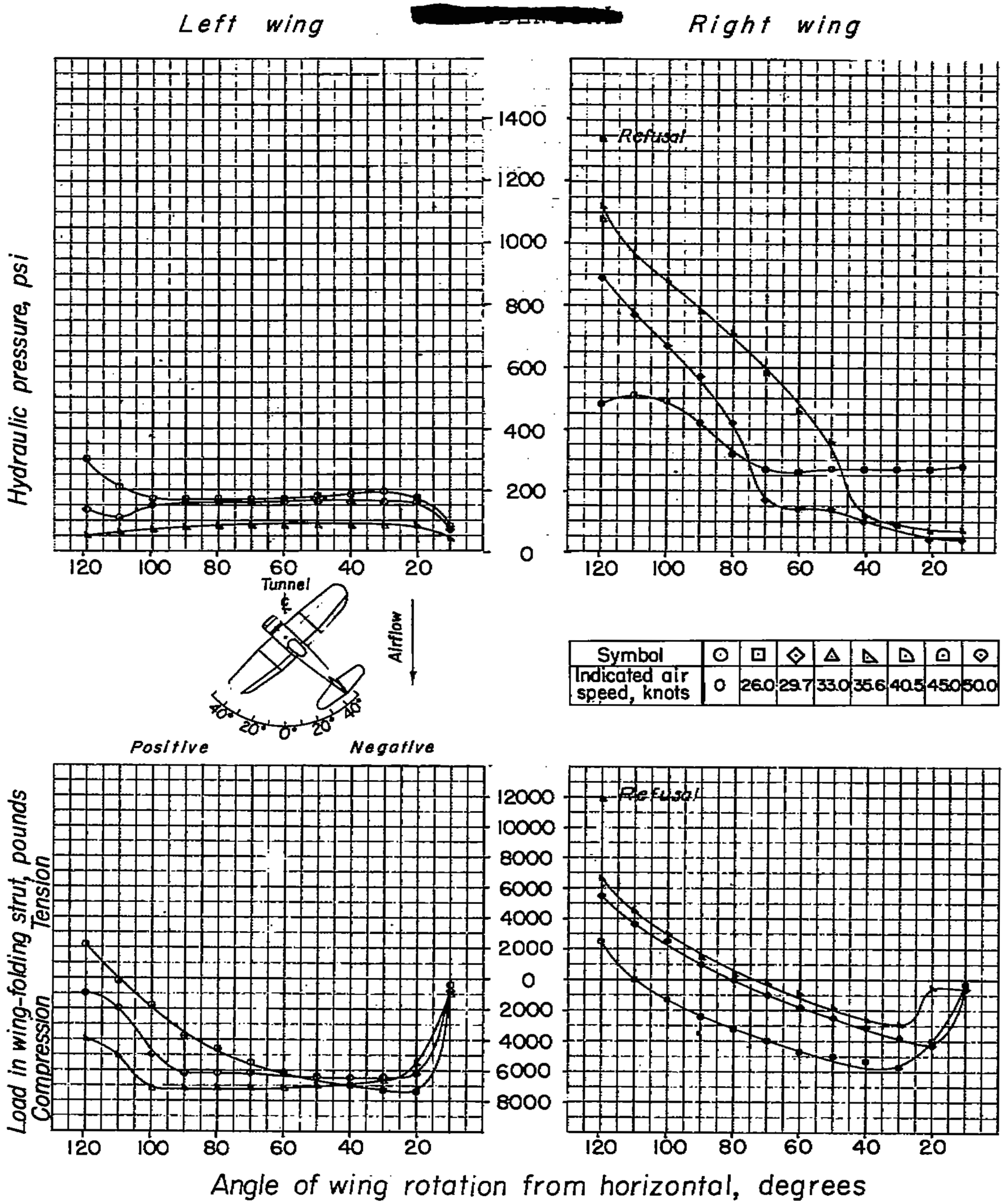

(b)— Spreading operation

Figure 21.- Concluded

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